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INTERNATIONAL RESEARCH CONFERENCE

13TH INTERNATIONAL RESEARCH CONFERENCE

HOLISTIC APPROACH TO NATIONAL GROWTH AND SECURITY

15TH - 16TH OCTOBER 2020

Engineering

PROCEEDINGS

General Sir John Kotelawala Defence University

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General Sir John Kotelawala Defence University

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Welcome Address

Major General Milinda Peiris RWP RSP USP ndc psc

Vice Chancellor, General Sir John Kotelawala Defence University

Honurable Minister of Education, Professor G L Peiris, the Chief Guest , Keynote Speaker, Secretary to the Ministry of Education, Professor Kpila Perera, Secretary to the Ministry of Foreign Affairs, Admiral Prof. Jayanath Colombage, Deputy Vice Chancellor (Def & Admin) Brig. Nanda Hathurusinghe, Deputy Vice Chancellor (Academic) Prof. Jayantha Ariyarathne, Deans of the respective Faculties, Directors of Centres, Academics, Senior Military Officers, Administrative Staff, Students and all distinguished guests who are connected with us in the cyber space.

First and foremost, let me very warmly welcome our chief guest, Hon Professor GL Peiris, Minister of Education for very kindly accepting our invitation and for gracing this occasion as the chief guest of this inaugural session of our international research conference 2020.

Sir, we consider your presence here this morning, as one of the most renowned scholars the country has ever produced in the field of Law, as a great honour to KDU. Let me also warmly welcome our keynote speaker, Prof Kapila Perera, Secretary to the Ministry of Education, who is having a very close affinity with KDU as an illustrious member of our alumni association.

Then I also welcome Admiral Professor Jayanath Colombage, Secretary to the Ministry of Foreign Affairs, and other distinguished guests and invitees participating on line as well. KDU, from its inception, was instrumental in handing down the core values of security to the development paradigm in Sri Lanka.

This year's theme 'Holistic Approach to National Growth and Security" highlights the importance of maintaining a harmonious blend in security and development in all national projects. As you are aware, this year's conference is taking place amidst very challenging circumstances, so much so that, it becomes a landmark event of KDU in terms of its resolution to ensure the continuity of events at KDU even under the most trying circumstances. And this conference is also significant because the year 2020 marks 40 years of existence of KDU since its inception in 1980.

KDU, initially established as a tri-service academy known then as KDA or Kotelawala Defence Academy, marked a significant diversion in 2008 with its renaming as General Sir John Kotelawala Defence University. Since then, with the guidance and vision of His Excellency the President Gotabaya Rajapakse, as the then Secretary to the Ministry of Defence and the Chairman of our Board of Management, KDU kept a giant leap forward to become a fully-fledged university with nine academic faculties and a University Hospital with state-of-the-art facilities. With this phenomenal change, KDU began expanding its horizon to provide its high-quality higher educational opportunities to civilian students, thereby reducing the burden on other state universities of the country in supplying for the higher educational demand in the country. Today, the University is ready to march forward steadfastly contributing to the national needs combining the national security domain with higher educational needs of the country.

Ladies and gentlemen, KDU international research conference has been attracting local and foreign presenters, participants and more importantly renowned scholars and professionals of the highest caliber both locally and internationally. However, in this year, the global pandemic situation has restricted having them physically present at KDU. But many of our invitees will join us on line to enrich the deliberations through this novel experience of having the conference on a virtual platform.

I reckon that this is a blessing in disguise for us to travel on untrodden paths for new discoveries. KDU IRC has been instrumental in establishing and strengthening the much needed research culture not only at KDU but also in the whole country.

We have been attracting papers from almost all universities, from many research institutions and other organizations representing even Batticaloa and Jaffna, which I reckon is a very encouraging sign. And the impact of the growing research culture was evident during the first breakout of Covid 19 earlier this year, where our staff and students were researching day and night for creating various products and inventions of our own to help the fight against Corona. So, it is heartening to note that in this year's conference, there are many research papers reaching the conference secretariat, which involve the student community of our nine faculties.

Therefore, we are proud that we have created a platform for emerging researchers and scientists for showcasing their research outcomes at KDU research conference. And it is our fervent belief that inculcating and fostering the research culture and enhancing the quality and quantity of research in various disciplines in the country can raise the resilience levels of society and the nation as a whole.

This year's conference has attracted six hundred and fifty plus paper submissions, which I believe is a very clear indication of the right enthusiasm growing in the country towards research, particularly in development and security domains. So we are proud as a university to be able to stand up resolutely to fulfill the needs of the nation, especially at a time when such efforts are very much needed. I believe the efforts of security-based education aiming at strengthening national development should be more cooperative in the future and KDU has always facilitated any research efforts that strengthens the national security of our nation. We urge the academic community of Sri Lanka to join hands with us in all our future endeavours to support the nation especially through productive research in diverse disciplines.

The organizers of the KDU international research conference intend to set the tone to initiate more collaborative research at national and global levels. This research conference is an ideal platform to make connections. I hope that authors of KDU and various other local and international universities will take the opportunity to interact and develop friendly relationships, establish networks and to explore win-win situations.

I wish all the very best for the presenters and hope you will enjoy every moment of this academic fusion taking place on two whole days.

Finally, let me once again welcome our chief guest and the keynote speaker on behalf of all KDU staff. I wish that presenters and participants would have all the courage to continue their pursuits with determination to link up with the international community and work towards national growth and development through their research.

Thank you.

Chief Guest's Speech

Prof. GL Peiris

Honourable Minister of Education, Government of Sri Lanka

Major General Milinda Peiris, Vice Chanceller of the Sir John Kotelawala Defence University of Sri Lanka, Admiral Professor Jayanath Colombage, Secretary to the Ministry of Foreign Affairs, Professor Kapila Perera, Secretary to the Ministry of Education, Deputy Vice Chancellors, Deans of Faculties, Heads of Department, members of the staff and students of this university, friends well wishers, ladies and gentlemen. I am delighted to be present with you on this occasion for the 13th International Research Conference. I am no stranger to these surroundings. I have been consistently associated with your work during the progress of your university until you have reached the stature that we all are proud of at this time. There is no doubt that with the nine fully-fledged faculties that you already have and your plans further to expand this university particularly bearing in mind the priorities of this country at this moment. I am particularly happy about your plans for the establishment of a Faculty of Criminal Justice. I think that is certainly an area that is worthy of focus and attention. So you have always assessed, evaluated very accurately the needs and priorities of our country in the field of Higher Education. And you have been very quick to respond to those needs. That innovative approach is much to be admired. And these are among the reasons why I have particular pleasure in joining you in these deliberations. There is one another matter that I would like to mention. It is this that you are having this conference for the 13th consecutive time. It is our experience in this country that many good things are planned and inaugurated. It is much more difficult to follow through. So the fact that you have been able to do this without interruptions for 13 years adding to your expertise as you go alone improving and expanding towards what you are attempting. It is greatly to be admired the sense of perseverance and determination that is greatly required in this country at this moment and your performance is an inspiring example of what we all need to carry the country forward to even greater heights.

Now the theme that you have chosen for this 13th International Conference is extremely appropriate from many points of view. You have heard representation from many countries as Major General Milinda Peiris, Vice Chancellor explained a moment ago. You are holding this conference in exceedingly challenging circumstances. Again you have been to adapt to difficult circumstances.You are resorting to modern technology to include and involve foreign participants in these deliberations even though they are unable to present with us physically on this occasion. The topic that you have chosen is the holistic approach to national growth and security. I think that is extremely relevant to present day needs in Sri Lanka today.

The first point I would like to make is that there is an intimate connection between national growth and security. It is fanciful to talk of any kind of national growth without the assurance of security. Security is a necessary and indispensable foundation. Without security it is impossible to achieve growth in any sector of the economy. The celebrated Political Scientist the late Professor Harold Laski of the London School of Economics said that the basic duty of a state is to provide security for its people. That is the ultimate reason for the existence of the nation state. The theory of the Social

Contract which has been developed by writers like Lock and Rousseau emphasizes the fact that the public have given the authority to state principally for the reason to create conditions in which life can go on in an orderly and frank manner so that the citizens of that state can realize their fullest potential as human beings, develop themselves and develop the community in which they live. In order to do this the essential condition is security. Without it nothing at all can be accomplished. Now we have seen empirical evidence of this in the recent past of our country through the 30-year conflict with the Liberation Tigers of Tamil Eelam. It was impossible to attract substantial investment into this country. Every facet of Sri Lanka's economy suffered grievously during that period. How can you attract investors into a country which has been thrown asunder by a ferocious war? Investment, international trade all this was affected by the ongoing conflict. I would also like to make a reference to the concept of reconciliation which became very relevant and important after the end of the war in 2009. There was then naturally the feeling that we have to leave the pain and anguish of the war behind us. We have to emphasize unity and the solidarity and bring together all the people of our cherished land irrespective of caste, creed, ethnic or religious identity to emphasize the oneness of the nation. That was the pith and substance of the concept of reconciliation. But it all went wrong during the *Yahapalana* administration of 2015 to 2019. And it is worth examining in an objective spirit the reasons why that endeavour failed so miserably. I think the basic reason is that the authorities at that time forgot the sentiments, the feelings and aspirations of the majority community. Reconciliation of course bases emphasis on minority aspirations to make them comfortable, to convey to them in definite terms the impression, the conviction that they are very much part of the country. They belong, the sense of belonging so that confidence should be imparted to minorities, and at the same time, it is absolutely necessary to carry the majority community with you. If you lead them behind if you engender in the lines of the majority community that they are not important, they can be sidelined, they do not matter, such an exercise in reconciliation is doomed to failure as empirical experience in those 4 years convincingly demonstrated. What happened during that period? I think the most alarming spectacle that we are seeing in this country today is evidence that is transpiring in daily basis before the Presidential Commission that is going into the catastrophic phenomenon of the Easter Sunday Attack. Evidence has been given by one witness after another, the Inspector General of Police, the Secretary to President, the Secretary of Defence, all these people. Their evidence emphasizes the total breakdown of this security apparatus in the country. It is not mere debilitation or weakening of security apparatus it was total collapse of it. There was no security apparatus functioning in this country at all in any realistic sense. So it led to the loss of 265 valuable lives of this country and crippling of many other citizens of our land. Why did this happen?

When the present President, His Excellency Gotabaya Rajapaksa was Secretary to the Ministry of Defense, there was a very close collaboration between the intelligence arm and immigration. Whenever an application was made by a foreign preacher somebody who wants to come and teach in this country, when visa was requested a very thorough background check was done. As Admiral Professor Jayanath Colombage would bear witness the antecedent of the person applying for the visa was thoroughly examined. And if there was anything unsavory in the past of that person, if he has been involved in any activity which led to

disharmony among communities, then the immigration authority in close consultation with the intelligence arm would turn down such a request for visa in this country. That whole apparatus was consciously and deliberately dismantled. It did not happen unwittingly or inadvertently. It was deliberate government policy. So intelligence personnel were made to feel that they were in embarrassment. The less that heard from them, the less they were seen the better. That was the environment which prevailed at that time.

Surely, if you are talking of national growth and security, the first thing to ensure is that funds that are coming from abroad had to be brought into the country through proper channels. We have in this country such an established conduit. The conduit is the External Resources Department of the Central Bank of Sri Lanka. Of course resources are welcome. But they must come through the External Resources Department. We must know the source, the origin of these fundsand where are these funds coming from? We must know the purpose for which these resources are going to be applied, who is going to manage these resources? There must be an auditor accounts. All of these were dispensed. You had a situation where a university was built. What is the purpose for a university to come up in Kattankudy. The facilities, the buildings that are constructed, they are better than the buildings that you have here at the Kotelawala Defence University. They are superior to the quality of the infrastructure in the universities of Colombo and Peradeniya. If you go to Kattankudy blindfolded if the blindfold is taken off when you get there, you will feel that you were in the Middle East. The Palmyra trees, the architecture the overall environment. The sums of money involved are colossal. There is no exposure, visibility or accountability. It is that brought about a situation that culminated in the total collapse of this security establishment. Madrasas can be all over the country. There are no Sunday Schools. They are providing many of them on daily basis. Nobody examines the curricula. There is no regulatory mechanism at all. So the seeds of racial hatred are sown by those institutions. Of course there must be freedom with regard to imparting instruction. But clearly there must be some supervision, some control, some regulation. That was totally lacking. So the country then paid the supreme price for the neglect of security in pursuit of narrow and particent and political objectives to placate aggressive minorities, not law abiding members of minority communities, but people who were intent on the destruction of the very social fabric of the country. So that was our sad experience.

This is true not only within the country, but also in the conduct of our foreign relations. What happened there? Sri Lanka is unique among the nations of this world in committing to a resolution in 2015 in the UN Human Rights Council. Sri Lanka became a co-sponsor of a resolution in condemning its own armed forces accusing its armed forces of the gravest crimes under international law and under the international humanitarian law because the preamble to resolution 13/1 of the 1st of September 2015 acknowledged with appreciation the report of the High Commissioner for Human Rights. And the High Commissioner's report makes the most damaging allegations against the armed forces of this country. And the government of Sri Lanka endorsed all of them and called for a thorough investigation at the international level. The resolution gave responsibility to the Human Rights Council and to the Commissioner for Human Rights to keep Sri Lanka under constant review. So here was a government which consciously, voluntarily, deliberately submitted the country to adjudication and assessment in respect of its armed forces to international tribunals

where justice considered the inanity of what happened. There were pledges given. In resolution 13/1 and 34/1 which are clearly contrary to the highest law of this country, the constitution of Sri Lanka operating para 6 of the first resolution 13/1 recommended that foreign judges of Commonwealth and other foreign judges should be entrusted with the task of judging our armed forces and of course, members of the civilian population. This is not possible under Sri Lanka's constitution because foreigners cannot exercise judicial power in respect of our citizens. And then the High Commissioner for Human Rights, Prince Hussein publicly conceded that in respect no other country has a Human Rights Council based in Geneva adopted so intrusive approach – so intrusive, interfering directly with domestic policy in that country. To what extent did this go? The resolutions involved matters which are clearly within the domain of the Sri Lanka's parliament not the business of foreigners. It called for constitutional reform. It called for devolution of greater powers to provincial councils. It called for thorough overhaul of Sri Lanka's armed forces and the police. It called for the repeal of the prevention of terrorism Act and its replacement by alternative legislation. Members of the Sri Lankan armed forces and the Sri Lankan police force were to be subjected to special criteria when they applied to join UN Peacekeeping forces abroad and even to enroll for programmes of training. So this is the extent to which national dignity and pride was compromised in order to placate foreign interests whose aims and objectives were incompatible with the well-being of this nation.

So this attitude which destroyed the very foundations of our national security manifested itself both in respect to domestic policy and the conduct of country's foreign relations during that period 2015 to 2019. In such a situation you cannot possibly have national growth. You cannot have economic advancement because security has broken down entirely.

Just one another point I want to make before I conclude, and that is the reference to militarization in the current political discourse. Non-governmental organizations and elements of the opposition as well as some prejudiced and biased foreign commentators are finding fault with the role of the military in the conduct of national affairs in Sri Lanka at this time. But no objective observer of the Sri Lankan scene can doubt the fact. When it came to the control of COVID-19, this country could not possibly have achieved what it did without the vigorous involvement and cooperation of the armed forces, particularly the intelligence arm. We were able to control the pandemic because the armed forces were able to identify those who have been infected, first the immediate circle and then the outer periphery. That is still being done, yesterday today it is being done. And the role of the armed forces is indispensable. Without them the situation would be far worse than it is. Why is there this kind of hostile attitude towards armed forces? I think people who subscribe to that point of view failed to distinguish between the culture of east and west in this regard. Cultural attitudes, assumptions and values are in critical significance in this area. The attitude in this country, the attitude of the public, of ordinary people, to the armed forces is not what prevails in some western countries. The armed forces are not looked upon with fear. They are not regarded as instruments of oppression. On the contrary, after the war ended in 2009, it is in effect the armed forces, they got involved very intimately, very vigorously in uplifting the social conditions in the people affected in areas. They built houses. They made water available. They played a role in restoration of agriculture. And I know personally because I have seen in

my own eyes that armed forces of this country even helped in the constructions of latrines, of toilets in that part of the country. These are not regular functions of the armed forces. But because of the culture of our country the social morals the value system based upon empathy and compassion which is the hallmark of Sri Lanka's culture. That was the nature of the role that was performed by the Sri Lankan military. It is this fundamental fact that is not taken into account. In critiques of the present scene who find fault with the armed forces forget their involvement in national activity on broader scale.

So these are some of the remarks that I would like to make to you on this occasion. I am very happy that you are having this 13th International Research Conference. I am very happy that you have chosen a topic that is extremely appropriate. You have chosen a more relevant topic for this time. As the Minister of Education also with the responsibility for higher education in this country, I am very proud of the achievements of your institution, what you have been able to accomplish within so brief a time span. The needs of higher education in this country are very urgent when more people are clammaering for access to higher education, in our ministry, with the active system of Professor Kapila Perera who is rendering a yeoman service in that regard, we are trying to bridge the gap between education and employment opportunity. We are talking to the major Chambers of Commerce they provide the jobs in the private sector to ascertain from them the employment opportunities that will be available in their institutions during next three or four years, what are the skills which we are looking for? Because they are telling me it is not that we do not have jobs to offer. We have jobs. But when we interview people we find that they don't have the skills which we want in our institutions. So we don't want to enhance a reservoir of angry and frustrated young people. We want to ensure that there is a co-relation between the education that is imparted in our institutions and the skills for which there is an identifiable demand in the market place. So these are some of the adventures that we have embarked upon. We are also looking critically at our curricula which are obsolete and anachronistic. They have not been revisited for a very long period. There must be in line with the needs of our society methods of teaching. There is far too much emphasis on rote learning in memory that students have required to commit their notes to memory, retain in the memory and reproduce it at the examination that is antithetic of the education. Education comes from Latin words '*educate*' which is draw out not to force in vast volume of actual material into mind of the students. So purpose of the education is to develop the analytical and the critical faculty of the student to encourage him or her to think for himself or herself and apply that volume of knowledge to face the challenges of life. So in the midst of all of this, in confronting the formidable challenges, I am very confident that your institution, Sir John Kotelawala Defence University will render an invaluable service. So I congratulate to you on your achievements of the past and I wish you well for the future. I know that you will continue to do your country proud. And I thank you sincerely for the honour that you have bestowed upon me by inviting me as the Chief Guest for these deliberations.

Thank you

Keynote Speech

Prof. Kapila Perera

Secretary, Ministry of Education, Government of Sri Lanka

Ayubowan! Wanakkam! Assalamu Alaikum! The Vice Chancellor of General Sir John Kotelawala Defence University, Major General Milinda Peiris, the Chief Guest today my honorable Minister, Ministry of Education, honorable Professor G.L. Peiris, Deputy Vice Chancellors, Deans of the Faculties, Heads of the departments, the Secretary to the Ministry of Foreign Affairs, Professor Admiral Jayanath Colombage, all the foreign participants who are joining this 13th International Research Conference at KDU, all the presenters, moderators, session chairs and all the distinguished invitees. Thank you very much for inviting me to deliver the Keynote Speech under the theme 'Holistic Approach to National Growth and Security.' I am indeed honored and privileged to be here having witnessed the very first one 13 years ago, and it happened to be General Milinda Peiris who was the Vice Chancellor then as Major General and we witnessed the presence of the Chief Guest as the Ministry of Higher Education, Ministry of Research and Technology.

I would like to start with this quote from the Chief Guest, "We do not want to have a reservoir of angry uncontented people." I was one who had gone through in 1971, of course not in the country in 1988 -1989 and then in then 1983 as a university student, and many times during my academic career where there were disruptions to education, holding back the desire to fulfill or acquire knowledge with my colleagues, peers and the rest of the people due to the lack of security. I know how I felt then as a student. I think I was in grade 4 in 1971, and then in 1983 in my second year at this very same premises, the education of ours were disrupted. And the feeling of those delays due to the lack of security, and the Cheif Guest elaborated in deep sense of comprehension how security is important for the national growth. If I look at what is this traditional approach that is often based on defensive security policies as we had during my time at different ages. We had always defensive security policies. However, the persistence of strong security measures generates inecure feelings. I hope you agree with me. If there are strong security measures that generate insecure feeling as it reveals the presence of threats. So these are some of the things that people quote. Then again the democracy, well-being and freedom are some of the elements that we feel that we reduce this feeling of insecurity by reducing both threats and activities that we feel. Even if you take a house if you feel this insecureness due to lack of security this might not allow you to think, generate analytical skills. You are always worried about the security. How to provide security to your children and for yourself? And then it hinders and it slows down entire process of nurturing, acquiring knowledge. And then that it is halting the growth. so you start from the small households or individuals then if you take as a whole family, a village, a township and then provinces as a country, it basically retards the national growth. So, therefore, we need to have this thinking of holistic approach to national growth and as you and I understand there are necessary and essential conditions when we learn mathematics for certain things. The Cheif Guest emphasized repeatedly the essential elements and in our academic mathematics there are sufficient and necessary

conditions or essential conditions for forming mathematical theories there are certain things. Likewise, it is essential to have security for national growth.

When it comes to economics, always and even for decades, the GDP strongly criticizes the measure of development. Still the role of economic systems neglecting the goal of global capabilities and expansion holds this economic growth or national growth. But the concession of development based on the glorification of individual success and the pushed capital accumulation hardly allows reducing insecurity and increasing freedom. So security becomes an individual good and relies upon ineffective defensive policies that we have practiced in the past unlike in the present. So development, well-being, security and freedom are strictly interrelated. Individual capabilities imply collective capabilities. Even in free market economies often human needs such as food, housing, employment, health care, family policies, fresh water, security and safety can be put in a market under regulation or collective governance, and those things even the Chief Guest highlighted. The need for water, need for food, how the security--food security and water security ensure the getting this national security when you combine all these types of security the national growth under war conditions. So these goods are often under political debate as they are critical for development and social cohesion. The more they are shared among the large part of the population the less we experience social conflict and political instability. Security hardly is achievable individually. It is the result of more holistic thinking. Individual security and freedom implies the security and freedom of all. As I mentioned before these are interrelated. And if you look at or if you study research and in future research all these studies can help in understanding human capabilities and pathways towards collective security and enhance development. So instances of participation in definition of security needs would make citizens able to feel at the center of development goals. So therefore, unlike in the past where we did not think holistically and the interrelations between the security and the national growth. Then we will fail. Even the theories in the literature highlights this one.

As far as Sri Lanka is concerned the contemporary security concerns that we face as an Indian Ocean country are broader and more complex, that need not be elaborated, than any state in our history. This will continue to exist. We can't say that this will stop today, tomorrow, next year or in ten years' time because the geopolitics and the race for the arms business and economic development, all these things will continue to grow, sometimes exponentialy. So therefore, national security cannot be neglected and cannot be just let it go as the Cheif Guest mentioned, even in a fraction of a second, it is very important. Otherwise there won't be any growth. As the Secretary to the Education, in the present context the role played by ensuring a secure environment for the student to go and sit the examination. They are not in a position to concentrate on answering the questions if the place is not secure. So if we are not able to hold the exams and continue to postpone, then we cannot achieve and we cannot predict national growth. So in this context the role played by the national security is to be commended as the Ministry of Education. I know personally the quick response to ensure secure examination centers for all of us for the future of Sri Lanka. Under these conditions even the identification of COVID origin in the recent past, you have to have peace of mind to concentrate on everything. That is basically if you only think of one place, one

center out of 2,646 examination centers, then there will be lack of security in different centers. So therefore, you have to think holistically. Only the one aspect of securing one place will not enable for us to continue this one and therefore the results will come in future in terms of national growth. So the range that concerns arise from threats to system that allows society to control intergroup and interpersonal conflict to more recently reorganized concerns associated with threats to social and economic systems. Once these events start to influence the policy and the economy of a country with a national resilience, that country will perish. One way of addressing this emerging situation is by promoting more and more research and development.

KDU, boasting with diverse nine faculties and through two new faculties to come, the Faculty of Criminal Law and the Faculty of Technology, is going to expand and provide opportunities and platforms for you to think, ponder in a military environment and inviting day-scholars giving the signal that is very important for you to mix each other understand the role of the military or security for the civilians, 22 million people in this country, how important the national security and the training in a military set up to achieve the common goal of national growth. So the KDU is at the forefront of researching the development and security related problems holistically. A holistic approach is needed to understand contemporary complex situations and circumstances. University education could inculcate co-values of security and development such as human dignity, integrity, democratic participation, sustainable development, economic equity, mutual understanding and respect and equality of opportunity. The three flags that are behind bring all three forces together, thanks to the KDA then, and how important this mutual understanding in the war was understood and it helped to coordinate things in a better manner. You trained officer cadets together and they understand the security roles in the air, at sea, on land. I am sure that it could have been the catalyst then. Now you bring the third aspect the day-scholars. So this is holistic thinking. Like I started at the beginning it was not there then. We had three academies that did not know each other, but how had it come during the time when the national security was at risk. So ultimately the beneficiary is national growth. The honorable Minister, the Cheif Guest mentioned how difficult it was for Sri Lanka to attract foreign direct investments. As I think Minister of Enterprise Development, Foreign Minister, Foreign Secretary. If you don't have security and thrust, nobody would come. But when you train together military and civilians with hand and hand, it would provide an ideal platform. The importance of civil-military relations and how KDU is instrumental in developing the above mentioned areas is to be commended. By promoting civil-military relations through education, a country could raise the resilience levels, like I mentioned, of communities. Honorable Minister spoke at length and elaborated that you have to have a strong commitment and the political will to ensure the security of this country. If these elements, instruments fail, the first thing that is going to effect is the education of the future generations. Even for me, the Oxford graduate, Rohdes scholar, I am a pupil. And this has provided opportunities and the responsibility to the government to ensure the security. So all spheres of activity will simultaneously grow ultimately culminating in national growth.

These are the few thoughts that I have to share with you. I would like to extend my gratitude on behalf of the Ministry of

Education for having me and inviting me to deliver the Keynote address and set the platform for the next two day deliberations. And I wish all the success in the deliberations and creating more networks and have future directions for years to come in this context of national security that you have chosen today. Whatever that you are going to do, base national security at the forefront. So divided we lose together we win. And I wish all the very best and thank you very much for all the participants and the people who have submitted papers, presenters, moderators, and session chairs. You are plying a very important role in this context of national security and the national growth.

Thank you very much!

Vote of Thanks

Dr. L Pradeep Kalansooriya

Conference Chair, 13th International Research Conference,
General Sir John Kotelawala Defence University

It is with deep appreciation and gratitude that I present this vote of thanks on behalf of the organizing committee of the 13th International Research Conference of the General Sir John Kotelawala Defence University.

First of all, I convey my heartiest thanks to Professor G.L. Peiris the Minister of Education, a distinguished academic who spared his valuable time with us on this occasion. Sir, your gracious presence amidst busy schedules is truly an encouragement and it certainly added the glamour and value to this important event.

Professor Kapila Perera, the Secretary to the ministry of Education, also a distinguishable academic and a senior military officer is a proud product from our own institute. Sir, I greatly appreciate your willingness without any hesitation to be our Keynote speaker today.

I would also like to take this opportunity to extend my appreciation and gratitude to the Vice Chancellor, Maj. General Milinda Peiris for all his guidance and assistance provided throughout the event and this event wouldn't have been a reality and a great success without your courageous leadership under the current challenging situation today.

I would be falling my duties if I don't mention the exceptional support and assistance provided by the two Deputy Vice Chancellors who were there behind the team guiding us through a difficult time. I also would like to thank the Deans of all the faculties who shared the responsibilities and guided their staff amidst their very busy schedules.

This year's conference has attracted six hundred and fifty plus paper submissions, which is a very clear indication of the right enthusiasm growing in the country towards research, particularly in development and security domains. I take this opportunity to thanks all authors share their studies on National Growth and Security in our conference. I also greatly appreciate our panel of reviewers on the valuable time spent to review this large number of papers. I'm sure that your valuable resnses would tremendeously supports to authors on enhancing their research studies.

Ladies and Gentlemen, as you witnessed, this was a new experience in the new normal, after the present pandemic, and therefore it was huge challenge to organize, coordinate and conduct research conference of this magnitude on virtual platform enabling a wider participation of both local and foreign participants. I thank all our participants attending the conference online despite numerous difficulties encountered due to the present situation.

Further, it is with great pleasure that I acknowledge the tremendous support and assistance provided by academic staff of all the faculties with all the Heads of Departments going beyond their regular duties to make this event a success. Similarly, I take this opportunity to appreciate the contribution of the administrative and non-academic staff whose commitment was essentially required in achieving the overall success.

Our sponsors, the financial support given by our Platinum Sponsors, People's Bank and

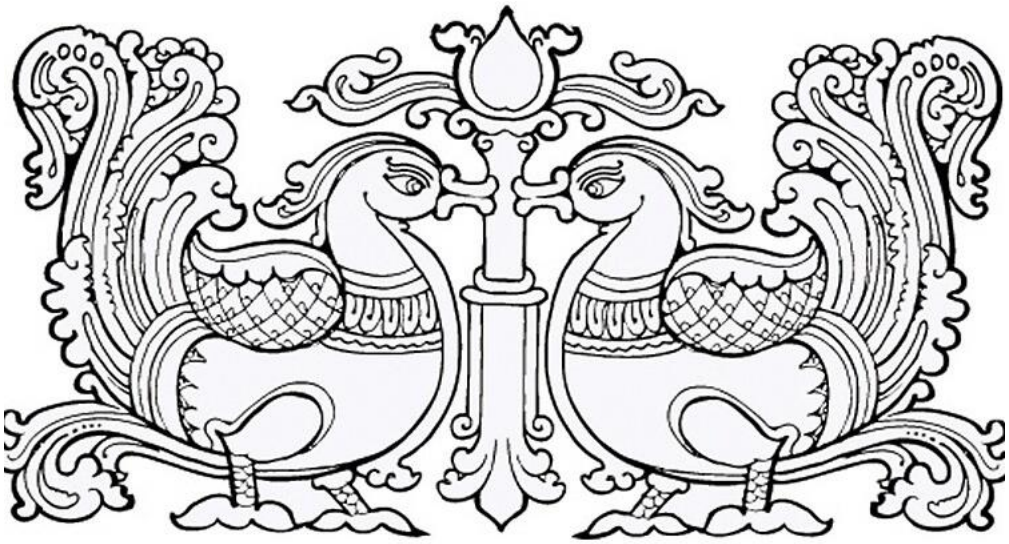
Bank of Ceylon and Co-sponsor, Abans Private Limited is highly appreciated.

Last but not least the officer cadets and day scholars who formed a very virtual component of the organizing teams in every sphere and I believe that it was a great learning experience and exposure which would help them tremendously in similar undertakings in the future.

Finally, I have no doubt that all of those attending the two days seminar will make the best use of the opportunity to enhance their horizons and establish new bonds and networking while sharing their own knowledge and experience in a friendly learning environment.

In conclusion, let me take this opportunity to profusely thank my co secretaries, who stood alongside me throughout extending unexplainable support and assistance with exceptional commitment.

Thank you so much. I wish you good luck and all the best.



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Technical Sessions

Paper ID: 06

Airline Maintenance Cost Optimization Through Spare Parts Inventory Control

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Abstract: Aircraft maintenance is a key factor which has a direct impact on the value and airworthiness of aircraft and plays an important role in strategical decision making which adjusts the economic performances. Managing spare parts efficiently through proper inventory controlling is critical for airlines in order to minimize total expenditure of maintenance and as a result, it has been persuasive to work further in detail on spare parts inventory controlling and optimization. The above process is followed to cater the airline production planning and a better scheduling of work can drastically minimize the maintenance cost. The research commences with studying what special practices are used to calculate demand for inventory and corresponding stock levels for the MRO activities. A comprehensive study is done on methods used to optimize spare parts inventory and efficient demand forecasting. The models presented throughout this research work are derived by studying the behavior of landing gear spare parts inventory controlling of an aircraft and can be applied to other systems' spare parts inventory controlling too. An area of interest that has emerged is that of Rotable, Repairable, Consumable and Expendable spares, which presents scope for research. With the current forecasting methods and help of the historical data, the proposed inventory controlling policies in this research, take into consideration, the reliability concerns and forecast demands depending on spare parts data from two directions: "lead time" and "mean demand". Hence, the optimum order number of units and ideal order period can be derived to understand the total minimization of expenditures, which results in a systematic optimization in the way of inventory controlling.

Keywords: Aircraft maintenance, Inventory controlling, Cost optimization

Introduction

In this research, it identifies four different types of aircraft spare parts as Rotable spare parts, Repairable spare parts, Consumable spare parts, Expendable spare parts. When the parts of aircraft systems fail or anyhow needs to be replaced, it generates a requirement for spare parts, and the requirement is fulfilled through the spare parts inventory. According to the expectation, above spares must be readily available in stock and those stock items should be refilled by extended processes such as repairing the reusable items or purchasing brand new . When the downtime is unplanned because of an unexpected breakdown, the results cause more damage. In some cases, disturbances in the operational procedure occur, as the flight scheduling is done based on the spare parts that are available in the inventories. This may cause decrease of service and idling time of other resources, other than the loss of production. In some instances, unexpected downtime will also generate safety hazards. As an example, when an aircraft has an unplanned grounding at the terminal, its scheduled flight should be postponed where passengers may lose their time, which may cause damages in customer

satisfaction and create empty seats; the take-off and landing slots assigned to that particular flight will be lost, causing disturbances to other flights; the crew for that flight should wait without any work, etc. As per the data collected by Federal Aviation Administration, flight delays cost the airline industry an average of 8 billion dollars annually. To reduce the grounding time, the spare part stocks must be efficiently maintained. This develops tremendous pressure on all parties connected with the aviation industry to carry out maintenance activities as efficiently as possible, which has created the space to present ideas that can reduce the grounding time of aircraft. Hence, the way to an efficient aircraft spare parts inventory controlling system is proposed through this research; considering many parameters related to spare parts inventory controlling.

Research Problem-

Airlines suffer a major cost due to aircraft spare parts. That cost is multiplied due to issues in inventory controlling. Therefore, this research is conducted to find a way to optimize the spare parts inventory controlling of an airline. This will be beneficial for airlines as well as approved maintenance organizations. Hence, the main research problem that arises is, "how to optimize the airline maintenance cost through spare parts inventory control?"

Objectives

The objectives of conducting this research are as follows.

• To develop a mechanism for the planning and control of a spare part supply chain in organizations that own and maintain equipment. This mechanism should include all the relevant decisions that should be made prior to purchase spare parts and it should explain how the decisions are related with each other.

• To identify the different types of spares used in aviation such as Rotable spare parts, Repairable spare parts, Expendable spare parts and Consumable spare parts that are significant in distinguishing various cost portions in maintenance.

• To analyze the key factors that affect efficient spare parts inventory control.

• Analyze the prevailing mechanisms and models which are relevant to spare parts inventory control and identify the issues/drawbacks incorporated with them.

• Suggesting a method to overcome the drawbacks of the systems and to bring them to the optimized state with respect to maintenance cost.

Methodology

The research group chose a survey research structure because it best served to solve the research questions and fulfilled the objectives of the study. The survey type data collection research is one in which a group of items are studied by gathering and analyzing data from only a random set of items which considered to be representing the whole group. Otherwise, only a random part of whole group is studied, and the results derived from this are expected to be applied to the entire group. In this research the group of items which were selected to study was the spare parts of the landing gear system of MA-60 aircraft i.e. the spare parts under "Chapter 32" of the MA-60 aircraft spare parts inventory. It was assumed that this particular group of spare parts will represent all the other spare parts of the MA-60 aircraft because Landing Gear system is a critical system and subjected to frequent maintenance activities with a number of fast-moving spares. Under the Chapter 32 of MA-60's spare parts inventory, 83 different spares were studied and the data related to those spare parts were collected and analyzed.

Results

The widely accepted method of calculating safety stock uses the statistical model of standard deviations of a normal distribution of numbers to determine probability. This statistical procedure has been tested and proved to be efficient and effective in calculating the best economical safety stocks in variety of operating conditions. The core for this calculation is standardized, however, its successful implementation to cater the requirements of this research needs customization of the formula and inputs to meet the specific characteristics of the Helitours (Pvt) Ltd operation.

First, the collected data from previously mentioned sources were entered to the MS Excel spreadsheet along with their,

- Part number
- Spare part name
- Expected and actual lead time
- Yearly demand
- Remaining stock as at end of each year
- Spare part unit cost
- Inventory holding cost
- Stock-out cost per trip
- Average trips per month

After entering the data to the spreadsheet, the following parameters were calculated for past seven years (i.e. 2011-2017) for each of the spare parts.

- Covariance of expected and actual lead times
- Combined standard deviation (σLT) of lead times
- Average lead time ($LTavg$)
- Monthly average demand (μ)
- Demand during lead time (DLT)
- Total inventory cost per year
- Total downtimes in terms of months
- Cost category (C)
- Service level(Q)
- Service factor (Z)
- Recommended safety stock (K)
- Re-order level (R)

Discussion

The existing methods for aircraft inventory planning which are being used by many approved maintenance organizations in Sri Lanka have many inherited drawbacks within them. Hence, this research was focused on developing an efficient spare parts inventory controlling method to forecast the time for re-ordering the spares with respect to lead time and mean demand of spares which is beneficial in maintaining inventories with high efficiency. Throughout the research, historical data of spare parts consumption for past seven years (from 2011 to 2017) were examined. Simultaneously, existing inventory controlling methods were studied and their drawbacks were identified. With reference to several studies, primary data and secondary data which collected, were analyzed using Statistical Model with Standard Deviation of a Normal Distribution. Using this method, mathematical relationships were derived and lead time and average demand analysis on each type of spare part related to the landing gear system of Xian MA-60 aircraft operated by Helitours, a reference to define a suitable safety stock and eventually a re-order point.

Conclusion

In this research, a statistical model of standard deviations of a normal distribution of numbers has been used to relate the variations in lead times to calculate the safety stock and in turn re-order point. Clarification of the statistical theoretical aspects which lies in the formula is necessary in correctly adapting it to meet the exact needs of the Helitours (Pvt) Ltd in terms of spare parts inventory control. Errors in implementation are usually the result of not factoring in variables which are not part of this statistical model. Also, a hypothetical service factor has been defined by considering the tradeoff between cost of inventory vs cost of stock-out. Hence the values obtained for recommended safety stock and re-order point have interconnection between the cost factors rather than having an arbitrary value for

service level. Further, the variations in the lead time has been considered by considering a stochastic variation and actual variation of it rather than taking the actual or expected lead time variations for the calculation of safety stock. Thus, the research team could obtain fair values for safety stock and re-order point for each of the spare part. As the conclusion it can be stated that by maintaining the safety stock and re-order points as recommended by the data analysis of this research will optimize maintenance cost of the airline (in this case it is Helitours (Pvt) Ltd). Note that airline maintenance cost would be optimized until such time the spare parts inventory managing personnel is making sure to maintain the safety stock and re-order point as recommended and not having excess or deficit amounts of spare parts other than recommended.

The developed statistical model and electronic spreadsheet are not only validated for the selected sample of spare parts, but also for optimization of all the spare parts in an inventory of an airline or an approved maintenance organization, thus fulfilling the main aim of the research.

This research has only discussed the lead time variations in this model. While operators or Approved Maintenance Organizations can use this model for predicting variations in demand for the spare parts, the research has found that demand for most of the spare parts tend to be far too random and unpredictable. Spare parts demand tends to be related more to an Approved Maintenance Programme which is constantly updating due to Service Bulletins, Airworthiness Directives, Service Information Letters and Maintenance Review Board Report and which in turn raises a non-stochastic demand rather than a demand which fall under the pattern of a normal distribution. However, if relationship which is approximate to the normal distribution could be found with respect to the variations in demand for the spare part, the safety stock conformed to that variation can be separately calculated and that value can be added to the recommended safety stock obtained by the statistical model used in this research.

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An Enumerative Constraint Planning Framework for Airline Engineering Manpower Cost Optimization

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Abstract: This paper discusses the formulation of a general enumerative constraint planning model relevant to different aspects of airline engineering workforce planning dimensions observed in the contemporary flight line operations. However, it is to be understood this is a general theoretical framework that needs to be custom-tailored to suit the diversified operational scenarios discussed therein.

Initially, evidential coherence of pre studied literature was comprehensively analyzed in ascertaining, understanding of predefined methodologies, and impediments of which. Whereupon the primary data elements are classified enlightened by said findings, and subsequently, relationships and the constraints related to data elements are discussed. It is followed by a discussion of the expected objectives and an employee-centered general model with the objective of direct or indirect cost optimization is formulated. Commuting on the contrived model, the amalgamation of a wide range of constraints has superseded the circumspection requirements of predefined models identified through literature. The general model signifies the complete aviation workforce planning problems from mediocre to prodigious cases.

Keywords: Enumerative constraint programming, Workforce Scheduling, Aviation management

Introduction:

Generally, workforce planning sequentially solve the interdependent decisions of staffing (i.e. estimating workforce capacity to meet the demand spanning through a longer horizon) and rostering (i.e. assigning employees to planned shift schedules) (Van Den Bergh et al., 2013). These two phases are constrained by an array of constraints related to cost, fairness, regulations, and general HR policies. Due to the computational complexity of the capacity assignment problem, different methods are used in literature where heuristics and enumerative programming are the most prominent (Al-Thani et al., 2016; Jamili, 2017). The complex calculation of the optimal equilibrium between skill-specific workload and capacity assignment in terms of ECP is discussed in Cuevas et al., (2016). A mixed-integer program is used to assign multiskilled employees for short term demand fulfillment with a modified version of the general tour scheduling problem. This enables management to assign simultaneous shifts and days-off for the heterogeneous workforce to cater to the firm's workload demand.

Research Objectives

The objective of any workforce scheduling problem is to employ available scarce resources most efficiently while attaining the job in the best possible quality at an optimal cost. However, the secondary level planning objectives are employee satisfaction, fairness in job distribution, optimal productivity, etc.

i. Minimization of operational cost without compensating operational reliability and quality.
ii. Ensuring fairness in workload distribution (including unpopular shift distribution) among employees.

Literature Review

A diverse array of computational methods have been used to solve different workforce planning problems where enumerative methods and heuristics are extensively used due to problem complexity and the exponential scale of the planning problem. Kasirzadeh, Saddoune, & Soumis (2014) present a detailed review of crew scheduling models and methods discussed since the year 2014. Bechtold (1981) distinguish linear programming and construction-based heuristics to be the main solution methods. Nevertheless, integer programming, decomposition, linear programming, metaheuristics, manual solutions, implicit modeling, goal programming, working set generation and construction/improvement methodologies have also been used significantly (Deng and Lin 2011; Iide, Ryan, and Ehrgott 2010). Also, Lavoie et al. (1988) formulate a large-scale set covering problem with many columns where each represents a valid crew pairing, and the authors propose a continuous relaxation to solve a scenario inclusive of 329 segments of flight legs through column generation method based on generalized linear programming. Ryan (1992) examines a generalized set partitioning model for aircrew scheduling involving more than 650 constraints and 200,000 binary variables. Yan & Chang (2002) discuss cockpit crew planning in specific as the salary and remuneration of the pilots cover a significant portion of overall crew costs where a set partitioning model is formulated to solve it through column generation. Deng & Lin (2011) use an ant-colony optimization-based algorithm to solve airline crew scheduling problems with various enumerations. Mercier & Soumis (2007) solve the optimal crew-scheduling problem along with aircraft routing and retiming. The above references confirm the fact that a vast majority of capacity planning and crew scheduling research are solved through complex mathematical methodologies.

As mentioned above, staffing phase estimates capacity according to the demand which generally spans through a longer planning horizon. The rostering phase assigns employees to planned shifts on a weekly or monthly basis (Van Den Bergh et al., 2013). The limiting constraints of these two processes are different as the scheduling constraints are process-oriented and staffing constraints depend on employee preferences and HR policies. Generally, mixed-integer linear programming (MILP), metaheuristics are used to solve these problems separately or simultaneously (Pinedo et al., 2015). Most MILP software use branch and bound enumeration framework to solve problems through LP relaxations. Also, integer programming column generation through a branch and price enumeration framework has emerged as a promising method for mid-size scheduling problems. However, real-world WP problems can hardly be solved optimally due to the NP-hardness of the problems (Heimerl & Kolisch, 2010). Therefore in recent literature, metaheuristic approaches also have gained popularity in finding feasible solutions within a reasonable computation time. It is also to be noted that metaheuristics, unlike the enumerative constraint programming, does not ensure a quality solution due to its implicit neighborhood search patterns (Brucker et al., 2011).

Methodology:

Initially, primary data elements are classified, and subsequently, relationships and the constraints related to data elements are discussed. It is followed by a discussion of the expected objectives and an employee-centered general model with the objective of direct or indirect cost optimization is formulated. Dependent and independent are the main two types of data elements in any WP problem, and a proper understanding of the distinction is essential in reducing the problem size, even though it seems trivial. At times, the data elements which are seemingly independent are dependent intrinsically (Brucker et al., 2011). On the other hand, some seemingly dependent elements have nothing to do with the other

elements. For a large airline sometimes it would be possible to divide the operational demand, terminal wise, to obtain an independent and smaller planning problem. As these solutions are mainly computer-based, the downsizing may not help the modeling problem but reduce computational time and enhance solution quality (Defraeye & Van Nieuwenhuyse, 2016; Van Den Bergh et al., 2013). The problem complexity dilution is always preferred than reducing the problem space especially for large scale planning problems (Wiegmann et al., 2017). The essential data elements of a general capacity planning problem are as below;

Data elements

1) Item(s) - The objects which are to be scheduled are items (e). It is important to note that at a time an "item" can only be in one place (Brucker et al., 2011). It has a unique identification supported by additional information. In most of the cases, an "item" in WP is an employee with different skills.

2) Block of Time (BOT) - A BOT(t) is a period during which an "item's" operation is planned. It must have a determined duration (i.e., start and end) and has properties like cost where a BOT is more generic than a "shift" as it may represent traveling time, meal brakes, etc (RAO, 1975).

3) Task/Job - A task/Job represents the composition of an "items" throughout a defined duration (BOT). An example of the simplest type of composition is the "requirement of two technicians for the night shift from 0000hrs to 0800hrs". However when logical operations like "and, or, not" are incorporated, the compositions get more complicated (Ernst et al., 2004). When the number and the type of items increase composed of different BOTs, the problem is no more trivial.

4) Costs - Every assignment of an item to a BOT will incur a cost. The costs associated with different pairings of items and BOTs vary (Periyar Selvam et al. 2013; Saltoɪlu, Humaira, and Inalhan 2016). For instance, the cost associated with assigning employees for a day shift is not equivalent to night or weekend shift assignment as they are relatively unpopular and therefore costlier. The cost of assigning (e) item to a (t) BOT is denoted by (c_{et}).

5) Decision variables - Assigning an optimal number of items to different BOTs at a minimal cost is the solution of a workforce plan. Such a solution can be represented by a binary variable set as below;

$$x_{et} = \begin{cases} 1 & \text{if (e)assigned to (t)} \\ 0 & \text{if otherwise} \end{cases} \quad \text{where } x_{et} \in X$$

and X denotes all decision variables

Constraints

In workforce planning, a diverse array of constraints are to be dealt with, and the same are categorized as "hard" and "soft" constraints followed by a set of variants.

1) Hard constraints - The ones which cannot be violated are the hard constraints. For instance, one employee can work only in one aircraft at any given time. This constraint for item (e) can be formulated as below;

$$\sum_{t \in T} x_{et} \leq 1 \quad \text{Where for } \forall T \qquad (1)$$

If (T) is a set of BOTs which overlap with each other, according to the inequality only one BOT can be selected at most as 0 & 1 are the only possible values for vthe ariable (x_{et}).

2) Soft constraints - Unlike hard constraints, the solutions are acceptable even with violated soft constraints. Nevertheless, it affects the solution quality and problem objectives. Hence it is vital to evaluate the level of violation and to understand how far a soft constraint can be bent in attaining a feasible solution. This could be achieved by associating a "violation coefficient." (v_c) with each soft constraint(c). It is to be further noted that ($v_c = 0$) when the soft constraint(c) is perfectly met and (th_c) is the threshold that defines an unacceptable level of violation.

c -Denotes soft constraint

v_c -Denotes violation coefficient associated to (c)

$v_c(X)$ -Denotes violation incurred to the solution (X) by soft constraint (c)

th_c -The denoted threshold of the maximum tolerated level of(c)'s violation

The above targets to get a feasible solution for(X) where $v_c(X) < th_c$ for every (c) and preferably, smaller the value of $v_c(X)$ is better. When there are more than one soft constraints a measure to be identified (C_{sof}) to represent the sum of violations. For optimal results C_{sof} should be minimal.

3) Sequence constraints - For a scheduling problem to be practical, one has to restrict BOTs with sequence constraints. When an employee is considered, it is evident that another 12-hour shift cannot immediately follow one shift with a duration of 12 hours. It is both against regulations and human endurance levels especially during unfavorable shifts (i.e. Nights & Weekends). For each BOT (t) one could define a set (T_t) which represents BOTs that could follow(t). If (T_t) represents all BOTs except BOT(t_1), then(t) could not be followed by (t_1) in the scheduling sequence for the same item (i.e., employee). Therefore a different sequence needs to be represented by a set (T_t) with only one BOT (t_2) where the workforce planner has no choice but to schedule (t) followed by(t_2). (T_t) Represents a set of BOTs that could be scheduled after BOT(t). Hence the formulation of the sequence constraint is as follows;

$$\sum_{t' \in T_t} x_{et'} \geq x_{et} \quad \text{for } \forall e, t \qquad (2)$$

Generally, the sequence constraints are hard, and the above inequality signifies that if item (e) is assigned to BOT (t) (then(x_{et}) = 1), at least a single BOT in T_t should be assigned to (t). So it is evident that the sum is always nonnegative.

4) Counting constraints - These are highly flexible type of constraints which count different things over variable BOTs. In most occasions, the counting results must fall within an acceptable range for the solution to be optimal. For example in most service organizations, accepted range of working hours span from 40 – 50 hours where the planning horizon would be seven days or a standard week starting from Monday. In addition, some other examples for counting constraints are specified ranges of unpopular shifts assigned to an employee over a planning horizon of one month and the available paid holidays for one year. Majority of the counting constraints are soft constraints and can be denoted by the function (f_c).

5) Work constraints - The primary purpose of WP is to get the work done in the best possible way. Therefore, work constraints are critical and may be either hard or soft depending on the type of problem. Mainly the work constraints are exclusive to individual problem settings and vary according to the definition of the job requirement. For example (e^{min}) is the least amount of items required to fulfill a job and (e^{max}) is the maximum items needed. (E) Is the set of all possible items which could be scheduled for the job and there is a set of BOTs (T) which are available to carry out the job and also it entirely cover job duration. In such setting the work constraint could be formulated as below;

$$e^{min} \leq \sum_{t \in T, e \in E} x_{et} \leq e^{max} \qquad (3)$$

6) Compatibility constraints - Some items cannot be assigned together to a same BOT due to compatibility issues. Such constraints are considered as compatibility constraints. For instance, there might be two employees who does not get along well with one another. If (I) denotes a set of mutually incompatible items and (J) represents incompatible sets of item (I) then the compatibility constraint formulation is as follows;

$$\sum_{e \in I} x_{et} \leq 1 \quad \text{where } \forall I \in J, \forall t \qquad (4)$$

7) Internal and external constraints - Internal constraints are demarcated by the nature of items which are to be scheduled while external constraints are governed by external environmental influences like administrative relations, labour laws, etc. For example the constraint that one employee could only work

in one place during a given BOT is an external constraint while a maximum number of work hours authorized by labour regulations are external constraints.

Objectives formulation

The objective function is the main element of a WP problem. This may comprise of multiple parts depending on the size and scope of the problem. The following can be highlighted as the main elements of a generalized objective function.

1) Cost - Minimization of operational cost without compensating reliability and quality is the primary objective of the majority of workforce planning problems. Here it is to be noted that cost and capacity are interrelated in the optimal capacity planning problem. The cost (C) is the sum of the set of all (X)assignments and is denoted as below;

$$C = \sum_{e,t} x_{et}\, c_{et} \qquad (5)$$

2) Fairness -Fairness in workload and unpopular shift distribution among employees is important. When doing this one needs a measure to evaluate the level of the unpopularity of a BOT (i.e., a shift) or the number of jobs assigned to a BOT. If (u_t) denote the measure of the unpopularity of a given BOT (t) we understand when (u_t) increase the unpopularity of the BOT (t) will increase accordingly. Therefore, when considering one employee, the unpopularity of a BOT (i.e. a shift) is formulated as below;

$$U_e = \beta_e \sum_t x_{et} u_t \qquad (6)$$

Here (β_e) is a workload coefficient as the unpopular shift distribution has to be inversely proportionate to the individual workload of employees. When considering all employees in an organization, if all values of (U_e) are equal then a 100% fair job distribution prevails. However, this is far from reality about any service organization. So an overall fairness measure (D_f) needs to be defined, and the difference between the best case and the worst case should be minimized.

$$D_f = \sum_t u_{t(\max)} - u_{t(\min)} \qquad (7)$$

If the job distribution is 100% fair the (D_f) will be zero and lower the value of (D_f) it is preferred as a better solution. Instead of the above, the standards deviation of (D_f) can also be considered.

3) Violation of soft constraints - The term "soft constraints" itself, indicate that satisfying all soft constraints are impossible. It is not practical to add them as constraints. Therefore a measure is to be defined how these soft constraints are respected while trying to optimize them. As a result, the soft constraints set becomes a sub-portion of the objective function. If the cost of all soft violations are denoted by(C_s);

$$C_s = \sum_c f_c\,(X) \qquad (8)$$

The above represents the summation of all soft constraints

Mathematical model formulation

As highlighted above, there are three elements to minimize; the cost associated on assignments of items to BOTs denoted by(C), measurement of overall job distribution unfairness (D_f) and measurement of cumulative soft violations(C_s). When considering an ideal situation, one could express measures of unfairness (D_f) and soft violations(C_s) in same units of assignment cost(C) by multiplying them by two constants (α_f) for fairness and (α_s) for soft violations. Then the overall objective function will appear as below;

$$F(X) = C(X) + \alpha_f D_f(X) + \alpha_s C_s(X) \qquad (9)$$

The following general model is a combination of all the elements discussed above. The model addresses the noncyclic homogeneous WP problems and can be adapted to solve a variety of real-world workforce planning issues. The formulation is as follows;

$$\text{Minimize } F(X) = C(X) + \alpha_f D_f(X) + \alpha_s C_s(X) \qquad (10)$$

$$\text{s.t.} \quad \sum_{t\in T} x_{et} \le 1 \quad \forall T, \forall e \qquad (11)$$

$$v_c(X) < th_c \quad \forall c \qquad (12)$$

$$\sum_{t' \in T_t} x_{et'} \geq x_{et} \text{ for } \forall e, \forall t \qquad (13)$$

$$\sum_{e \in I} x_{et} \leq 1 \text{ where } \forall I \in J, \forall t \qquad (14)$$

$$e^{min} \leq \sum_{t \in T, e \in E} x_{et} \leq e^{max} \qquad (15)$$

$$x_{et} \in \{0,1\} \qquad (16)$$

Discussion:

Equation (10) is the objective function where it minimizes the overall cost associated item assignments, fairness violations, and soft violations. It is to be noted that Equation (11) denotes (T) set of BOTs which overlap with each other, and according to the inequality only one BOT can be selected at most as 0 & 1 are the only possible values for the variable(x_{et}). Equation (12) denotes a feasible solution for(X) where $v_c(X) < th_c$ for every (c) and preferably, smaller the value of $v_c(X)$ is better. Equation (13) denotes that if item (e) is assigned to BOT (t) (then(x_{et}) = 1), at least a single BOT in T_t should be assigned to (t). so it is obvious that the sum is always nonnegative. Equation (14) denotes (I) a set of mutually incompatible items and (J) represents incompatible sets of the item (I) then the compatibility constraint formulation is given in the equation. Equation (15) denotes the work constraints. For an example (e^{min}) is the least amount of items required to fulfill a job and (e^{max}) is the maximum items needed. (E) Is the set of all possible items which could be scheduled for the job and there is a set of BOTs (T) that are available to carry out the job and also it entirely covers job duration. Equation (16) denotes,

$x_{et} = \begin{cases} 1 & \text{if (e)assigned to (t)} \\ 0 & \text{if otherwise} \end{cases}$ where $x_{et} \in$ X and X denotes all decision variables

where $x_{et} \in X$ and X denotes all decision variables.

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Effect on Water Quality due to Residential Development – A Case Study on Kolonnawa Canal

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Abstract: Due to the increasing number of residential buildings in Colombo and its suburbs, the wastewater volume generated and discharged by them is also to be increased. It would affect water bodies and would eventually lead them to be heavily polluted. As the canal network which is a part of the surface drainage system in Colombo acts to drain out the flood water from Colombo to the sea and Kelani river while providing and receiving water from urban wetlands, their water quality should be properly monitored and controlled.

This study attempted to measure surface water quality in Kolonnawa canal, find out the Grey Water Footprint (GWF) and analyse the effect caused by the domestic wastewater discharged into Kolonnawa canal and its marsh. This study is conducted by using water quality parameters including pH, Temperature, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Total Dissolved Solid (TDS), Electrical Conductivity (EC), Salinity, Resistivity, Chemical Oxygen Demand (COD), NO_3-N and PO_4-P and ultimately finding the GWF by collecting 3 sets of samples from 8 locations at 10-day intervals. Test results indicated DO, BOD and COD as downgrading water quality parameters showcasing major differences from allowable water quality standard values. GWF is calculated as 131.25 m^3/s, a considerably high discharge rate which could only be achieved in flood situations. According to the water quality results and site investigations, it was concluded that the Kolonnawa canal receives a considerable load of pollutants from its sub-catchment and domestic originated greywater is a major contributor

Keywords: Grey Water Footprint, Water Quality, Colombo Canal System, Kolonnawa Canal

Introduction

Over the past few years, the residential development in Sri Lanka is arriving to a peak. Condominium and apartment units are now being built or have been planned to be built in Colombo and its suburbs and may spread into the other major cities as well (Ariyawansa et al. 2018). Although the development of residential settlements is high, an average of 10-15% of the housing stock in suburban cities of Colombo are at substandard quality. With the increasing trend of urban sprawl and population growth in Colombo, its suburbs will have more residential land use in the future (UN Habitat, 2018).

Unlike those modern housing units, most average residential settlements in urban and suburban areas of Colombo does not have access to sewerages which is only covering the Colombo Municipal Council boundary and also in need of rehabilitation. According to the existing practice, domestic wastewater from the areas where sewerage networks are not available, disposes onto the ground with or without onsite treatment or into the surface drainage network, waterways or marshes (Ministry of Housing & Construction of the Government of Democratic Socialist Republic of Sri Lanka, 2018).

Colombo city depends on its 20km^2 of wetlands for fresh and wastewater management, biodiversity protection, flood mitigation, ecosystem services such as recreation, air quality maintenance etc.;

they are also essential parts of the city infrastructure. Despite of their importance, 50% of the Colombo wetland network was in a very bad quality. 15% of the network had a bad water quality. 15% and 20% of the network had medium and good water qualities respectively. The pollution increase was growing faster from 2010 and the overall actual water quality was poor (Ministry of Megapolis and Western Development, 2016b). Colombo canal network is a part of this surface drainage system which drains out flood water from Colombo to sea and Kelani river (Moufar and Perera 2018).

For the purpose of water quality analysis in the study, the selected geographical scope is an area belongs to the sub-catchment to Kolonnawa canal which has an area of 5.43 km^2. Sub-catchment in Figure 1 is the collection of four Metro Colombo Wetland (MCW) zones namely, MCW 06 (Kolonnawa East-Gothatuwa), MCW 07 (Kolonnawa South-Madinnagoda), MCW 11 (Kolonnawa-West Salamulla) and MCW 12 (Kolonnawa-West Yakbedda).

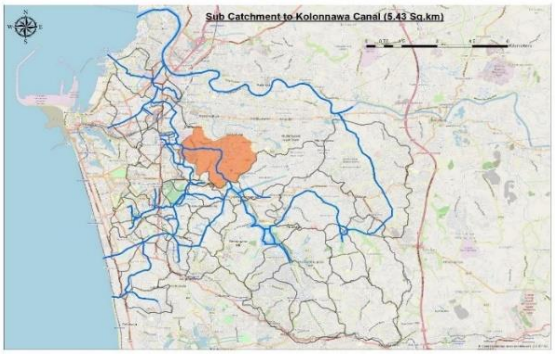

Figure 1- Selected Geographical Scope Sub-catchment to Kolonnawa Canal

Colombo Canal Network

Colombo canal network is a 67km long complex interconnected system of natural and manmade open canals, lakes and marshes. The canal beds have zero slope and lay -1m above Mean Sea Level. The Parliament lake is considered as the head of the Colombo canal system. The main canals in the system are, Kolonnawa Ela, Heen Ela, Kotte Ela, Mahawatte Ela, Wellawatta canal, Dehiwala canal, Torrington canal, St. Sebastian canal, Dematagoda canal, Kirulapona canal, Bolgoda canal and main drain. 400ha of flood retention marshes are attached to the system which consist of Kolonnawa marsh, Heen Ela marsh and Kotte Ela marsh (Anurangi et al, 2011).

For the purpose of developing the software "Water Quality Monitor", a water quality assessment has been carried out for the Colombo canal system. Monthly measurements of 10 water quality parameters including BOD_5, COD, DO, Nitrate, Phosphates, Ammonia, pH, conductivity, turbidity and temperature has been done in 20 locations. It was concluded that the Colombo north canal system is more polluted than the south canal system and the pollution level of the grid area should be lowered by introducing proper solid waste management, wastewater treatment and sewage treatment facilities (Eriyagama and Ratnayake 2008).

Grey Water Footprint

Water Footprint (WF) is a concept introduced by Hoekstra (2002). It is a comprehensive multidimensional indicator of the direct and indirect use of freshwater. There are three components of WF as Blue, Green and Grey Water Footprints. The WF is a volumetric measure of water consumption and pollution but not a measure of how severe the impact of consumption and pollution are for the local water system. It can be used in a vast range from a single product to a whole nation. GWF was introduced to express pollution as volume polluted to facilitate the comparison between the volume consumed and polluted. It is calculated by the following equation (Aldaya et al., 2012).

$$GWF = L/Lcrit \times R \quad ...(1)$$

L – Pollutant load entering a water body (mass/time)

$Lcrit$ – Critical load (mass/time)

R – Runoff, flow rate of the water body (volume/time)

GWF – Grey water footprint (volume/time)

$$Lcrit = R \times (Cmax - Cnat) \quad ...(2)$$

Cmax - Maximum acceptable concentration of the pollutant (mass/volume)

Cnat – Natural concentration of the pollutant in receiving water body (mass/volume)

An assessment of water use and total pollution load in Kelani river within the Western province has been conducted by Sri Lanka Land Reclamation and Development Corporation (SLLRDC) as a part of "Every Drop Matters" project aiming to control pollution in Kelani river basin. All the pollution and consumption points in the study area have been identified and GWF has been calculated using the total pollutant load. Policies and technical solutions have been made to reduce the pollution within the study area. GWF had been calculated according to the baseline accounting method. The points where branch rivers/ canals discharge their water flow into Kelani river were considered as the point source pollutions from each sub-catchment area. Any non-point source pollutant in subcatchments were considered to be mixed with branches before reaching the discharge point. A total of 16 sub-catchments were considered (Sri Lanka Land Reclamation and Development Corporation, 2015).

Methodology

Selected canal segment in this study holds a significant importance as it is a part of few major development projects in Sri Lanka. It is also attached to the Kolonnawa marsh which is a part of Ramsar recognised wetlands in Colombo Wetland City. Parts of its sub-catchment area are included in large scale projects such as Commercial City Development Project, Capital City Development Project and Rajagiriya Elevated Highway Project. (Urban Development Authority, 2019a; Urban Development Authority, 2019b; Road Development Authority,2019)

A. Water Sample Testing

Selection of sampling locations was done based on several factors. In order to calculate GWF, pollutant loads coming into the canal were to be found. Since there are many waterways which bring water to the canal and marsh, testing water quality and flow rate of each and every one of them for baseline method of GWF calculation was not practical. Therefore, water quality and flow rate of the canal was directly tested and measured from the canal itself form several locations which hold significant importance. As the quality of water which comes through residential areas was needed to be assessed, some peripheral waterways which receive residential wastewater were also selected. Other than these reasons, ease of access also played a significant role on location selection as many discharge points of smaller waterways were not easily accessible. Sampling points shown in Figure 2 were selected across the Kolonnawa canal and its peripheral water canals due to the reasons shown in Table 1. Water quality parameters pH, DO, BOD_5, TDS, EC, COD, salinity, conductivity, temperature, NO_3-N and PO_4-P as defined by Environmental Protection Agency, (2001) were checked at these locations. Three sets of data were collected with 10 days intervals. The collected data were used to analyse the

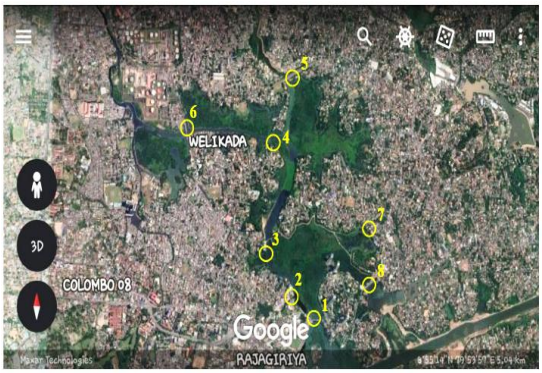

Figure 2 - Locations of Water Quality Measuring Points

quality of water that gets discharged into Kolonnawa canal and marsh from residential areas against ambient water quality standards and calculate GWF of the Kolonnawa canal.

Table 1 - Location Justification

Location	Justification
1	Inflow to sub catchment of Kolonnawa canal
2	Small waterway on left canal bank
3	Small waterway on left canal bank
4	Intersection of Kolonnawa canal and waterway to Kittampahuwa canal
5	Harward Bund, Inflow to Kittampahuwa Canal
6	Outflow from sub catchment of Kolonnawa Canal
7	Small waterway on right canal bank
8	Small waterway on right canal bank

Besides BOD_5, COD, NO_3-N and PO_4-P, all the other parameters were measured on site between 10.00am-12.00pm using HACH HQ40d Portable Multimeter and 3 probes. A quantity of 2.5l water from each location was taken for laboratory testing. Laboratory testing for COD, NO_3-N and PO_4-P were done by the SLLRDC laboratory at Attidiya. BOD_5 was tested at the Central Engineering Consultancy Bureau (CECB) laboratory at Colombo 05.

B. Ambient Water Quality Standard

For the calculation of GWF, Central Environment Authority (CEA) provided water quality were used. As the study area is to be developed as a linear park, transportation network etc. and is currently serving as a source of biodiversity preservation zone, the quality of water was checked against "Category C" which is defined for fish and aquatic life water by Central Environmental Authority, (2018) and Department of Government Printing, (2019).

Flow Rates

Centre for Urban Water Sri Lanka (CUrW), which has been set up for Metro Colombo Urban Development Project (MCUDP) has a system for obtaining real time water level data from several water level stations. These data are observed from water level gauges based in IOT and also available to general public. The stations include, Janakala Kendraya, Diyasaru gate upstream, Ingurukade, Wellampitiya, Wellawatta, Diyasaru Uyana, Ranwala Bridge and Yakbedda (Curwsl.org, 2019). Station Yakbedda coincides with the sampling location 6. From that, real time water level of sample location 6 was obtained.

As this is the only available water level measuring station in the study area, canal water flow rates of sampling locations were obtained based on it. In order to do that, data from Ministry of Megapolis and Western Development, (2016a) was used. The report has provided with data of hydraulic functions of several wetlands for different storm events. Data of three cross sections of the Kolonnawa canal and marsh were obtained. From real time water level of location 6, storm event was assumed. Flow rates of the above indicated three locations for that specific storm event were then obtained from the data set available in the hydraulic report.

Reults and Discussion

A. Water Quality

Table 2 - Onsite Water Quality Measurments

Location	Day	Temperature (°C)	pH	Conductivity (µS/cm)	Salinity (‰)	Resistivity (kΩ/cm)	TDS (mg/l)	DO (mg/l)
1	1	29.8	7.88	229.0	0.11	4.47	109.2	5.31
	2	28.5	8.40	168.0	0.08	5.95	79.7	5.76
	3	28.4	7.49	423.0	0.20	2.36	204.0	3.72
2	1	28.9	8.64	282.0	0.13	3.54	134.8	3.42
	2	28.4	8.29	178.6	0.08	5.60	84.8	5.65
	3	26.9	7.41	488.0	0.23	2.04	236.0	0.88
3	1	30.1	7.95	309.0	0.15	3.24	147.7	4.30
	2	27.8	8.45	176.0	0.08	5.68	83.8	3.99
	3	28.0	7.47	432.0	0.21	2.32	208.4	0.53
4	1	30.4	7.84	366.0	0.17	2.73	176.1	8.87
	2	28.7	8.37	217.0	0.10	4.61	103.2	4.13
	3	28.3	7.30	497.0	0.24	2.01	240.0	0.33

5	1	30.3	7.99	316.0	0.15	3.17	151.4	4.29
	2	28.0	8.76	307.0	0.14	3.27	146.3	2.41
	3	26.1	7.53	371.0	0.17	2.72	177.5	2.38
6	1	30.8	8.01	322.0	0.15	3.10	154.3	6.13
	2	27.7	7.65	264.0	0.12	3.78	126.7	0.85
	3	28.7	8.38	526.0	0.25	1.90	255.0	0.28
7	1	28.0	7.95	373.0	0.18	2.68	179.4	3.02
	2	28.5	8.40	168.0	0.08	5.95	79.7	5.76
	3	27.8	8.06	385.0	0.18	2.60	185.2	1.39
8	1	30.1	7.85	223.0	0.10	4.46	106.8	9.64
	2	29.4	8.07	207.5	0.10	4.82	98.7	9.45
	3	28.9	8.38	287.0	0.14	3.49	137.2	11.23

When considering the measured water quality across the canal and sub catchment, results in Table 2 could be concluded as follows. Temperature of surface water is within the range of 31-26˚C. pH value varies within the range 7.3-8.76. Except for 2 occasions among 24 samples, pH value is in the range of required standard 6-8.5. There are no specified standards for conductivity, salinity and resistivity for this category. It could be seen that maximum value of conductivity 526 µS/cm results from a salinity of 0.25‰ which is a far less value than in salty water. It also results the lowest resistivity value of 1.9 kΩ/cm. Minimum value of conductivity measured is 168 µS/cm which has been resulted from a salinity of 0.08‰. The highest resistivity related to those values is measured as 5.95 kΩ/cm.

Total dissolved solid concentration also doesn't have a specified standard value in the ambient water quality standards. Maximum value is measured as 255 mg/l and minimum value is measured as 79.7 mg/l. However, except for location 5 and 8, all other locations showed a gap of more than 100 mg/l in value between their maximum and minimum measured TDS values. From that it could be concluded that the TDS values vary significantly in a single location with time.

According to the water quality standard, DO value of a water sample is required to be equal or above 5 mg/l at 25˚C temperature in fish and aquatic life waters. However, only 9 occasions out of 24 gave a satisfactory DO value. From 8 locations, only the location 8 had a constantly high DO value which also provided the highest measured DO value of 11.23 mg/l. Every other location also indicated a deterioration of DO value. In some locations, the DO value drastically change through the 3 sampling days. In location 6, the DO value went from 6.13 to 0.28 mg/l which was the lowest measured value and in location 4, it went from 8.87 to 0.33 mg/l. These values however are measured at the respective water temperatures of each location as they were measured onsite. Low DO values could be resulted due to different reasons. Water being too warm, high amount of bacteria, excess amount of BOD, fertilizer runoff, taking samples in the morning hours and relatively still water as the flow rate was low could be some of the reasons.

Table 3 gives the results of BOD_5, COD, NO_3-N and PO_4-P tests. From the values is clearly visible that both biochemical and chemical oxygen demands are well above the allowable values. The maximum BOD_5 value of 80 mg/l is recorded from the outlet of the Kolonnawa canal. Compared to that, the inlet BOD values are much lower. Therefore, it could be concluded that the catchment adds a pollutant load to the canal. The minimum value of BOD_5 is 4.2 mg/l which is still above the minimum standard. COD values are always higher than that of BOD. The highest value is 140 mg/l while the lowest is 18 mg/l. As Nitrate and Phosphate concentrations are very low and within the allowable standard limits, it can be seen that the oxygen demands are not for oxidation of those nutrients but of other pollutants.

Table 3 - Laboratory Tested Water Quality Measurements

Location	Day	BOD_5 (mg/l)	COD (mg/l)	NO_3-N (mg/l)	PO_4-P (mg/l)
1	1	30.0	48	0.7	0.1
	2	15.0	32	0.9	0.1
	3	20.0	77	0.1	0.3
2	1	4.2	27	0.6	0.1
	2	17.0	33	0.9	0.1
	3	55.0	140	0.1	1.2
3	1	35.0	66	0.6	0.1
	2	18.0	21	0.8	0.1
	3	55.0	85	0.2	0.3
4	1	35.0	42	0.5	0.2
	2	17.0	39	0.7	0.1
	3	45.0	89	0.1	2.1
5	1	30.0	48	0.6	0.1
	2	19.0	38	0.6	0.1
	3	60.0	56	0.1	0.1
6	1	50.0	68	0.5	0.5
	2	17.0	28	0.7	0.4
	3	80.0	130	0.1	2.7
7	1	17.7	43	1.1	0.2
	2	22.0	46	1.1	0.1
	3	28.3	76	1.2	0.7
8	1	15.0	18	1	0.1
	2	18.0	38	0.9	0.1
	3	40.0	63	0.3	0.1

B. Flow Rates

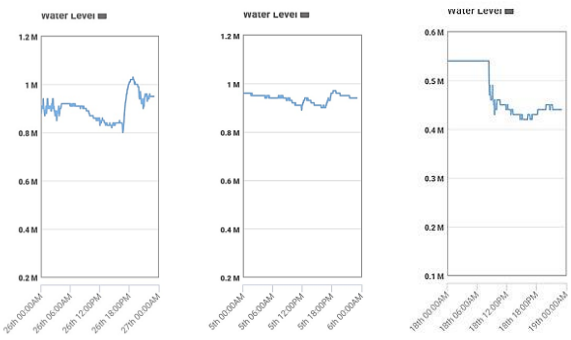

Figure 3 shows the flow water levels at sample location 6 for 3 sampling days taken from CUrW. From that, water levels were taken as 0.9m for first 2 days and the final day had a water level of 0.5m.

These water levels were similar to the 2 year favourable flood condition and dry condition in Kolonnawa canal according to Ministry of Megapolis and Western Development, (2016a). Figure 4 shows the canal cross section and flow data near sample location 6.

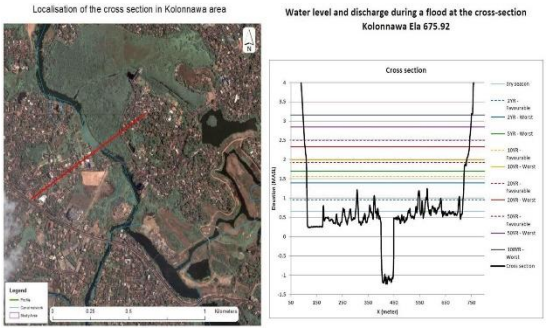

Figure 4 - Canal Cross Section and Water Levels for Different Storm Events of Sapmle Location 6

Data in Table 4 were obtained for the water level variations on the days of sampling collection.

Table 4 - Flow Rates

Location	Flow Rate (m^3/s) Day 1	Flow Rate (m3/s) Day 2	Flow Rate (m3/s) Day 3
1	8.5	8.5	4
4	6	6	3.5
6	10.5	10.5	5

Table 5 - GWF Calculation Day 1

Location	Pollutant	Concentration (mg/l)	Flow Rate (m3/s)	L=Ceff*Deff (mg/s)	Cmax (mg/l)	Cnat (mg/l)	GWF=L/(Cmax-Cnat) (l/s)	GWFmax (m3/s)
1	BOD	30.0	8.5	255000	4	0	63750	63.750
	COD	48		408000	15	0	27200	
	NO3	0.7		5950	10	0	595	
	PO4	0.1		850	0.4	0	2125	
4	BOD	35.0	6	210000	4	0	52500	52.500
	COD	42		252000	15	0	16800	
	NO3	0.5		3000	10	0	300	
	PO4	0.2		1200	0.4	0	3000	
6	BOD	50.0	10.5	525000	4	0	131250	131.250
	COD	68		714000	15	0	47600	
	NO3	0.5		5250	10	0	525	
	PO4	0.5		5250	0.4	0	13125	

Table 6 - GWF Calculation Day 2

Location	Pollutant	Concentration (mg/l)	Flow Rate (m3/s)	L=Ceff*Deff (mg/s)	Cmax (mg/l)	Cnat (mg/l)	GWF=L/(Cmax-Cnat) (l/s)	GWFmax (m3/s)
1	BOD	15.0	8.5	127500	4	0	31875	31.875
	COD	32		272000	15	0	18133	
	NO3	0.9		7650	10	0	765	
	PO4	0.1		850	0.4	0	2125	
4	BOD	17.0	6	102000	4	0	25500	25.500
	COD	39		234000	15	0	15600	
	NO3	0.7		4200	10	0	420	
	PO4	0.1		600	0.4	0	1500	
6	BOD	17.0	10.5	178500	4	0	44625	44.625
	COD	28		294000	15	0	19600	
	NO3	0.7		7350	10	0	735	
	PO4	0.4		4200	0.4	0	10500	

Table 7 - GWF Calculation Day 3

Location	Pollutant	Concentration (mg/l)	Flow Rate (m3/s)	L=Ceff*Deff (mg/s)	Cmax (mg/l)	Cnat (mg/l)	GWF=L/(Cmax-Cnat) (l/s)	GWFmax (m3/s)
1	BOD	20.0	4	80000	4	0	20000	20.533
	COD	77		308000	15	0	20533	
	NO3	0.1		400	10	0	40	
	PO4	0.3		1200	0.4	0	3000	
4	BOD	45.0	3.5	157500	4	0	39375	39.375
	COD	89		311500	15	0	20766	
	NO3	0.1		350	10	0	35	
	PO4	2.1		7350	0.4	0	18375	
6	BOD	80.0	5	400000	4	0	100000	100.000
	COD	130		650000	15	0	43333	
	NO3	0.1		500	10	0	50	
	PO4	2.7		13500	0.4	0	33750	

According to the above tabulated calculations in Table 5, Table 6 and Table 7, the GWF of Kolonnawa Canal could be taken as 131.25m^3/s which means that the water flow rate of Kolonnawa canal should reach the value 131.25m^3/s for the pollutant load to be assimilated and diluted down to the acceptable pollutant concentration. It is the highest GWF value in the sample. It can be also recognized that the GWF is depending on the BOD_5 value of samples. Therefore, even when the COD value is higher, it has not been represented in the maximum GWF values.

The other important finding is that the GWF of catchment outflow location is always higher than the other 2 locations. It can be concluded that the catchment itself adds a load of pollutants to the canal. These pollutant concentrations may get reduced due to the ecological functions of the surrounding wetland. At the Location-4 which is in the middle of the canal path and connecting to another comparatively large water body (canal), the GWF had a lower value in first 2 sampling days. Although the pollutant concentration seems to be reduced at that location, it again goes into a higher value at the next location which is the catchment outlet.

Rest of the five locations were analysed to recognise characteristics of water that flow into the Kolonnawa canal and marsh, also of the water flowing into Kittampahuwa canal.

Conclusion and Recommendations

According to the above analysed results it could be seen that the water quality of the outflow from the catchment through Kolonnawa canal is worse than the water quality of the inflow into the catchment. It could be concluded that the catchment gathers a certain pollutant load to the canal through its way down. Some peripheral canals through residential zones are polluted and they discharge their pollutant loads into the Kolonnawa canal directly or through the marsh. Even though the marsh generally acts as a method of reducing pollutant concentrations from water, the canal still receives a pollutant load from residential wastewater. To dilute the pollutant concentrations to an acceptable value, flow of the canal must be higher than 131.25 m^3/s. As it means, in flood

situations, the water quality of the canal could get better.

For a better water quality in the Kolonnawa canal and its marsh, pollutant load coming to them must be reduced. In many locations it could be seen that the residential wastewater discharge points are connected to peripheral canals rather than the Kolonnawa main canal. These connections must be regularised with certain quality measures if not connecting them to a central sewerage collecting system and then discharging after necessary treatments. Also solid waste dumping to the marsh and canals should be stopped.

During the flushing of north canal system, if it would take a longer time than ideal, Kolonnawa canal should also be pumped with water in order to maintain a better water quality as it cut downs both inflow and outflow of the catchment. Cleaning of the canal should be conducted regularly to control plant growth on the canal water surface.

NWSDB of Sri Lanka already have some projects to build more sewerage connections to the areas where they are required. Even though the entire study area in still not included in those projects, Kolonnawa UC is being considered as an area which requires sewerage pipeline connection. SLLRDC is maintaining the wetland marsh and canal network and have been able to reduce the amount of solid waste dumping into the wetland in some areas significantly.

As a part of this canal segment acts as a boundary to the Commercial City Development Project and Capital City Development Project, it is important to know the behaviour of water quality in the canal due to different land use patterns of its catchment. Also the quality of water will affect the Rajagiriya Elevated Highway Project form the start of construction and to the end of its design life.

The water quality of Kolonnawa canal could be measured throughout a year for different storm event conditions to figure out how the pollutant concentrations in canal changes with the different water levels and discharges. Also peripheral canals could be regularly checked with land use pattern and population changes. A study could also be conducted to recognise the effect on the catchment caused by blocking of flows during flushing of Colombo north canal system.

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Proper Management of Quarry Dust that is Generated in Crusher Plants as Waste

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Abstract: Quarry dust is the by-product produced due to the crushing procedure of stone crushing industry. The unavailability of a proper disposal method to this quarry dust is a huge problem faced by crusher plants. If this quarry dust can be used as a useful product it will be a good solution for this issue. It might be able to use as a substitute material for natural sand in preparation of cement mortar. In this research, a new cement mortar with an adequate quantity of quarry dust as a partial replacement of natural sand was designed. The effect of partial replacement of natural sand with quarry dust on the strength of cement mortar was studied. Here 1:5 cement:mortar mixture with 0.5 water:cement ratio was used as the standard test specimen and another five test specimens were tested by varying the quantity of quarry dust from 15% to 55% out of total sand volume at 10% intervals with varying water:cement ratio from 0.51 to 0.55 at 0.01 intervals with the increment of the quarry dust quantity respectively by keeping cement quantity and temperature constant. The cement mortar exhibits excellent strength with 45% replacement of natural sand with quarry dust with water: cement ratio 0.54.

Keywords: Quarry dust, Cement mortar, Natural sand

Introduction

The stone crushing industry is one of the widely spread industries in Sri Lanka. It produces aggregates with different desired sizes required for various construction activities. It provides many job opportunities for the people and for the people and also it is one of the main industries which has a great contribution to the economy of the country. The stone crushing industry is expected to be growing day by day due to the increase of demand for the aggregates due to the large number of construction activities that are carrying out throughout the country. In Sri Lanka, there can be seen both large and small scale stone crushers.

Quarry dust is the waste material that is generated due to the crushing process in stone crushing plants. It is

abundantly available due to the unavailability of a proper disposal method. It is stored as large stockpiles in crusher plants. Usually in a crusher plant for a day a huge quantity of quarry dust is produced. Therefore it occupies a large land area and this is a huge problem faced by crusher plants due to the limited land area available. If this quarry dust can be used as a useful product, it will be a good solution for this issue.

Today due to the rapid growth in the construction industry, there's a scarcity of construction materials and sand is a good example of it. The usage of quarry dust as an alternative material for natural sand in preparation of cement mortar could solve issues related to the disposal of quarry dust and also it will be a good solution to the scarcity of natural sand. This research was carried out based on this concept and a new cement mortar mixture was designed by using quarry dust as a partial replacement material for natural sand.

A. Research Significance

Introducing a proper waste management system for quarry dust generated in crusher plants is the aim of this study. This is very important for present crusher plants in Sri Lanka. Because the unavailability of a proper disposal method to dispose quarry dust is a huge problem faced by crusher plants. Due to that quarry dust is stored as large stoke piles and it occupies a large land area.

But due to the unavailability of sufficient land area to store quarry dust it is very essential to find out a proper method to dispose of it. If this quarry dust can be used for a useful purpose then it will be a good solution for this issue. This research was carried out based on this concept. Here, a new cement mortar mixture was designed by substituting natural sand with quarry dust. If it can be successfully implemented then it will be a good solution not only for the above issue but also it will be a good precaution to conserve natural resources. The shortage of natural sand is one of the major problems faced by the construction industry. Therefore the usage of quarry dust as a substitute material for natural sand will be a good solution to the scarcity of natural sand. Due to the shortage of natural sand its cost also considerably high and this is hugely affecting the construction activities. But when comparing with natural sand quarry dust is a cheap material. Therefore by using quarry dust, the quantity of natural sand that is required for construction purposes such as in preparation in cement mortar, concrete can be reduced and due to that cost can be reduced to a considerable extent. Due to the huge generation of quarry dust in a crusher plant for a day its availability is also high compared to natural sand and also since it is considered as a waste material, it is easily obtainable and no need to spend money to produce it.

Methodology

Methodology of this research can be divided into 2 phases;

01). Data collection

This was carried out in two steps;

i) Primary data-Questionnaire and Interview
ii) Secondary data-Sieve analysis test and Compressive strength test

02). Design of cement mortar mixture

A new cement mortar mixture with an adequate quantity of quarry dust will be designed using the test results of laboratory tests.

Questionnaire

The questionnaire was distributed among 10 randomly selected crusher plants in Kurunegala district. The questionnaire consisted of 14 questions. The purpose of the questionnaire was to find out the average rock crushing rate of a crusher plant, production rates of different sized aggregates, measures taken to minimize the quarry dust generation, measures taken to prevent the spreading of quarry dust, methods followed by crusher plants to store quarry dust, Current disposal methods followed by crusher plants to dispose quarry dust, issues related to disposal of quarry dust.

Interview

An interview was conducted with a relevant official in the Provincial Environmental Authority of North Western Province. The purpose of conducting an interview was to find out what are the rules and regulations related to establishment and operation of a crusher plant, clearances that must be obtained by a crusher plant for its establishment, criteria that must be followed by a crusher plant in diposal of the waste that is generated during its operation etc. When considering about the clearances that required to establish a crusher plant, through the interview information such as; the procedure that must be followed to obtain

the relevant license, the procedure of applying for those licenses including the time periods that the applications must be submitted to obtain those licenses, investigations that are carrying out to provide approvals for the establishment of a crusher plant were collected. Also through the interview information like; the regulations and criteria that a crusher plant must follow in waste disposal, the measures that must be taken to prevent the spread of dust with the wind, investigations carried out by relevant officials to investigate whether crusher plants are functioning according to the relevant rules and regulations, were gathered.

Sieve Analysis Test

In the cement mortar mixture which was designed two fine aggregates were used. They were natural sand and quarry dust. Here the type of sand which used was River sand. The Sieve analysis test was carried out for both River sand and quarry dust samples. The specifications that were used to carry out the test were; ASTM C 33-03 : Standard Specification for Concrete Aggregate, ASTM C 136-06 : Standard Test Method for Sieve Analysis of Fine and Coarse Aggregate, ASTM C 117-95 : Standard Test Method for Materials Finer than 75µm(No.200) Sieve in Mineral Aggregate by Washing.

First, the Sieve analysis test was carried out for River sand sample. Here since the sand sample contains particles which pass through 75µm sieve first, the weight of the particles that pass through 75µm sieve was determined according to ASTM C 117-95 specification. First, the sample was oven-dried at a temperature of 110 ± 5°C for 12 hours. Then the mass (W1) of the sample was measured using a balance. After that, the sample was placed on a container and a sufficient amount of water was added to cover the sample. Then the sample was agitated to separate the particles that are finer than 75µm, from the particles coarser than 75µm. After that, the wash water containing the suspended and dissolved solids was poured over the 75µm(No.200) and 1.18mm(No.16) sieves. Here the 1.18mm sieve was placed on the 75µm sieve. Then again water was added to the sand sample and it was washed as before. This procedure was repeated until the wash water became clear. After that sand retained on the nested sieves was returned to the washed sample by flushing.

Then the washed sample was oven-dried at a temperature of 110 ± 5°C for 12 hours. After sand sample got dried mass was measured using the balance (W2) and then the mass of the particles which passed through 75µm sieve was calculated by W1-W2. The total mass of the particles which pass through the 75µm sieve will be calculated by adding this value with the mass of the particles that passed through the 75µm sieve during dry sieving of the sample. Then this oven-dried sample was sieved again using a sieve set it was agitated using mechanical shaker. The sieves were selected according to ASTMC 33-03. The test was carried out according to ASTM C 136-06.

After that, the retained mass on each sieve was measured and using that the mass passing through each sieve was found. Then the passing percentages of each sieve was calculated. Here the total mass of the sample was taken as W1. Finally, the particle size distribution of the sand sample was plotted by graphing the passing percentage of each sieve with the sieve opening size and if this graph lies in between the Upper limit and Lower limit graphs, then

the sample will be adequate to be used in the preparation of cement mortar. These Upper limit and Lower limit are defined in ASTM C 33-03. The same procedure was carried out for quarry dust sample to determine the particle size distribution of the sample.

Compressive Strength Test

For the cement mortar mixture, the Compressive strength test was carried out for both 7 and 28 days. The test was carried out according to ASTM C 109/ C 109M-02 – Standard Test Method for Compressive Strength of Hydraulic Cement Mortar (Using 2-in or [50mm] Cube Specimens). The cement mortar samples were prepared by varying the quantity of quarry dust added and from each cement mortar sample, 3 test cubes were casted for each 7 and 28 days compressive strength tests. Here 1:5 Cement: Sand mortar mixture with 0.5 Water: Cement ratio (Specimen with 0% quarry dust added) was kept as the standard test specimen. Here 1:5 cement: sand ratio and 0.5 water: cement ratio was given in volume-wise. In other five specimens, the quarry dust quantity was varied by 15%, 25%, 35%, 45% and 55% out of total sand volume and water: Cement ratio was varied from 0.51, 0.52, 0.53,0.54 and 0.55 respectively by keeping the cement quantity, and the temperature constant. The quantity of water added was increased with the quantity of quarry dust added. Because when increasing the quarry dust quantity water absorption of quarry dust increases. Therefore, if the water quantity does not increase with the quarry dust quantity added there will be no sufficient amount of water for the hydration process of cement mortar and due to that it may not gain sufficient strength and cracks may occur. The test was carried out under normal room temperature. Here Portland Limestone cement was used and water was obtained from the water supply line. Here the quarry dust sample was obtained from a crusher plant. A sample of which particle size lies in between the upper and lower limits defined in ASTM C 33 – 03 specifications was prepared by sieving. This was done because from crusher plant to crusher plant the quarry dust samples that generating are different and even in the same crusher plant it varies. Therefore as a solution for that quarry dust sample was prepared using the above procedure.

For the casting of Cement mortar test cubes 50mm x 50mm x 50mm cube moulds were used. A thin coating of a releasing agent was applied on the interior faces of the cube mould and then it was placed on the base plate. After that, a watertight sealant was applied at the outside contact lines between the mould and base plate. Then the first layer of cement mortar sample was placed about 25mm of the mould depth and it was tamped using a tamping rod by giving 32 strokes within 10s in about 4 rounds. Then the second layer was placed and it was tamped in the same way. Next, the top surface of the cement mortar cube specimen was placed and it was level by using the flat side of a trowel. Here the test cubes for both 7 days and 28 days tests were casted together. After casting, the test specimens were kept for setting for 24 hours. After 24 hours the cube moulds were removed and the test cubes were cured by soaking inside a water container (7 and 28 days). The temperature of the water was maintained at 23 ± 2°C. After curing, all the specimens were wiped well. Then the specimens were kept on the Compressive strength test machine. Then the load was applied at a rate of 900 to 1800 N/S. The load was applied on the test cubes until it starts cracking and at the cracking point load was recorded. Then the compressive strength of each specimen was calculated and using that the average value of the compressive strength of each 3 test specimens of each cement mortar mixture was calculated for both 7 and 28 days.

Results and Discussion

Through the questionnaire it was found that out of 10 crusher plants 60% are Cone crushers, 20% are Jaw crushers and another 20% have both Cone and Jaw crushers. When considering the quarry dust generation, the dust generation rate of a cone crusher is higher than a jaw crusher. When considering

the monthly boulders crushing rates of crusher plants 80% of crusher plants have a crushing rate of 5000-15,000m^3/month. 30% of crusher plants generate 20%-30% of quarry dust out of the total crushing rate of boulders per month. When considering the current disposal methods followed by crusher plants to dispose quarry dust 40% of crusher plants do not have any issue with the disposal of quarry dust. These crusher plants dispose quarry dust by selling it to manufacture concrete fence posts, concrete blocks and in preparation of concrete etc. But 60% of crusher plants do not have any proper method to dispose quarry dust. Therefore these crusher plants have to stockpile quarry dust for about one month or more. Since there is no enough space to stockpile this quarry dust there is a huge necessity of finding a proper disposal method of quarry dust for these crusher plants. When it comes to the measures taken to minimize the spreading of quarry dust with the wind in most of the crusher plants they have used methods such as; covering of crushing units with dust barriers, covering of crusher plant boundary using rubble walls, Properly covering the stockpiles of aggregates etc. When considering the measures taken to minimize the generation of quarry dust in most of the crusher plants they have used methods such as; usage of water sprinklers at the crushing units, water spraying at quarry and feeding units, adjusting crushing units to minimize dust generation and wet crushing process. In some of the crusher plants, it was observed that they haven't taken any measures to minimize dust generation. Then the issues related to the stockpiling of quarry dust are; the spread of dust with wind and lack of enough space to stock quarry dust.

Then through the interview the information such as; clearances that required for the establishment of crusher plant, rules and regulations related to the sound and dust emission of a crusher plant. There are 3 clearances that required for a crusher plant for its establishment. They are; Environmental clearance which is issued by Central Environmental Authority or Provincial Environmental Authority and it must be obtained before installing the crusher plant, Environmental Protection License(EPL) which is issued by Central Environmental Authority or Provincial Environmental Authority and it must be obtained within one month of its installment and it is valid for 6 months or 1 year, Trade License which is issued by Pradeshiya Sabha and it is valid for 1 year. When considering the rules and regulations related to the sound emission; the permissible sound limit at site boundary is 55dß, soundproofing of generators using canopies or placing inside a fully covered room which is constructed with a 9-inch hollow brick wall, proper Maintainance of all other noise-generating machinery and equipment to minimize noise generation, carrying out of all high noise generating operations inside closed chambers. The rules and regulations related to dust emission are; must spray water into the feeding and crushing units using water sprinklers, must locate stockpiles of aggregates behind wind barriers, must keep the stones on the stockpiles sufficiently wet by water spraying, must spray water on to the ground using water sprinklers and bowsers etc.

The test results of Sieve analysis tests are as follows;

River sand sample

Sieve analysis test was carried out for a River sand sample with dry weight 695.2g. The grading curve of the river sand sample is given below, which was plotted by using the test results of the Sieve analysis test.

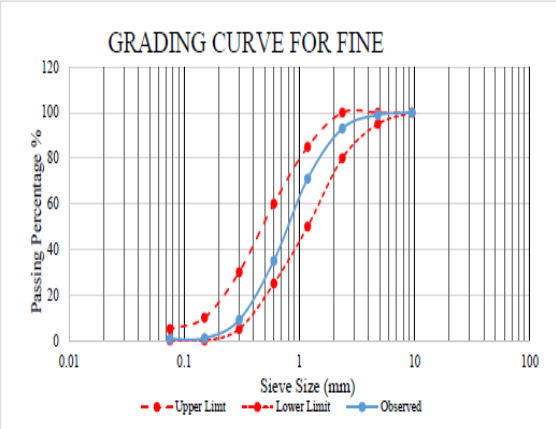

Figure 1. Particle size distribution curve of the River sand sample

The two red-coloured curves depict the upper and lower limits that have defined in ASTM C 33-03. The particle size gradation curve must lie in between these specific limits. The blue-coloured curve depicts the particle size distribution curve of the River sand sample and since it lies in between these two curves it is adequate to be used in the preparation of cement mortar.

Quarry dust sample

Sieve analysis test was carried out for a Quarry dust sample with weight 678.52g. The grading curve of the quarry dust sample is given below, which was plotted by using the test results of the Sieve analysis test.

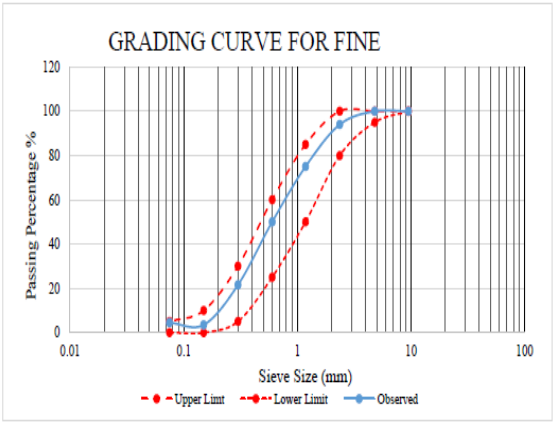

Figure 2. Particle size distribution curve of the Quarry dust sample

Since the particle size distribution curve lies in between two specific limits curves it is adequate to be used in the preparation of cement mortar.

The test results of 7 and 28 days Compressive strength tests are as follows;

7 days Compressive strength test

The test results of 7 days compressive strength test is illustrated in the graph given below.

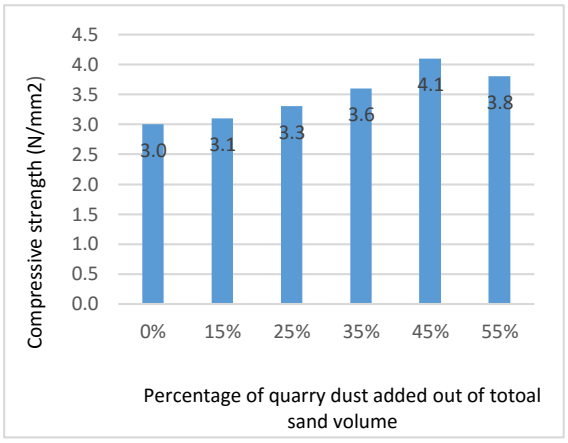

Figure 3. Compressive strength test (7 days)

Here the compressive strength of each cement mortar mixture was calculated by taking the average value of its 3 samples. The cement mortar mixture with 45% quarry dust and 0.54 Water: Cement ratio has the highest compressive strength and it is 36.67% greater than the compressive strength of standard cement mortar mixture.

The compressive strength of cement mortar samples increases with the quantity of quarry dust and it has increased up to 45% but after that, it has started to reduce. This may be due to the fact that 45% replacement of natural sand by quarry dust may show the optimum reaction with optimum filler capacity.

28 days Compressive strength test

The test results of 28 days compressive strength test is illustrated in the graph given below.

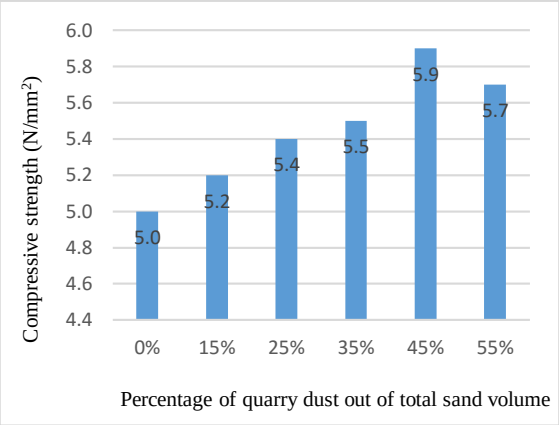

Figure 4. Compressive strength test (28 days)

The mortar mixture with 45% quarry dust and 0.54 Water:Cement ratio has the highest compressive strength and it is 18% greater than the compressive strength of standard mortar mixture. The strength of mortar samples increases when the quantity of quarry dust was increased up to 45% but after that, it has started to decrease. Also, the compressive strength of all samples has increased with the curing period.

In 28 days test results also, the compressive strength of cement mortar samples increases with the quantity of quarry dust and it has increased up to 45% but after that, it has started to reduce.

Therefore using the test results of both 7 and 28 days compressive strength tests it can be concluded that 45% replacement of natural sand by quarry dust will yield the maximum strength for cement mortar and therefore the suitable quantity of quarry dust to replace natural sand is 45% out of its total volume.

Conclusion

The main aim of this research was to come up with a proper waste management method for the quarry dust generated in crusher plants of Sri Lanka as a waste. Usage of quarry dust as a substitute construction material is one of the good methods to dispose of quarry dust properly and this research was done based on this concept.

In this research there were 3 main objectives such as; to find out what are the disposal methods follow by crusher plants for quarry dust disposal, to design a new mortar mixture by substituting sand using stone dust, to examine the variation of properties of mortar with the variation of the quarry dust quantity added.

The first objective was achieved through the Questionnaire. The questionnaire was distributed to 10 randomly selected crusher plants in Kurunegala district. It was found that 40% of crusher plants dispose of quarry dust by selling, to produce various products like concrete blocks, concrete fence posts, concrete, etc. But 60% of crusher plants do not have a proper waste management system. Therefore they have stockpile quarry dust that is generated in crusher plants, for about 1 month or more.

The second and third objectives of the research were achieved through Sieve Analysis Test and Compressive Strength Test (7 and 28 days). It was found that the adequate quantity of quarry dust that can be used to replace the natural sand is 45% through the test results of both 7 and 28 days compressive strength tests. The compressive strength of this test sample was 4.1N/mm^2 and it was 36.67% greater than the standard test sample in the 7 days compressive strength test and in 28 days compressive strength test it was found that the compressive strength of this test sample was 5.9 N/mm^2 and it was 18% greater than the standard test sample. The water: cement ratio of this sample was 0.54. The test results show that the compressive strength of cement mortar increases with the quantity of quarry dust added but after a certain point (45% stone dust) strength starts to decrease. Therefore quarry is suitable for the partial replacement of natural sand and not the full replacement.

Therefore quarry dust is a good alternative to partially substitute natural sand when preparing cement mortar and this will also be a good solution for the scarcity of natural

sand. Also nowadays sand is a very costly material, therefore this will be a good solution to reduce construction costs because it is more cheaper than sand. Also, over-extraction of sand from river beds cause deepening of river beds which lead to the occurrence of bank slides, affecting agriculture, disturbs aquatic plants and organisms etc.

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Optimum Locations Suitability: Analysis for Tsunami Warning Centres

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Abstract: More than 35,000 lives were lost due to the Tsunami disaster, occurred in 2004. That time, early warning towers had not been established to warn people before this kind of a disaster. After the disaster, 77 early warning towers were established in the coastal area of the country. Geographic Information System (GIS) can be identified as a tool which has the capability of providing most recent and accurate information which is necessary for making most suitable decisions for a problem. As well as a mapping system which has been developed for storing, analysing, modifying and displaying spatial data of any place existing in the entire world. GIS has become a very useful tool which can be used in the vulnerability and hazard assessments. A research based on GIS Analysis has been done to find out the optimum locations to the Tsunami early warning towers located in between coastal line of Matara and Dickwella. It has been identified the most vulnerable areas for a future Tsunami disaster and has done an analysis to check the coverage of the existing Tsunami towers. Finally, a comparison between the optimum locations and the existing locations has been done and has identified the areas which have no protection from a future Tsunami disaster in the research area.

Keywords: Optimum location, Tsunami Early Warning Tower, Vulnerable areas

Introduction:

"Tsunami" was a new word for Sri Lankans till 26th of December 2004. About eighteen (18) countries around the Indian Ocean like India, Indonesia, Malaysia, Bangladesh, Thailand and Sri Lanka have been affected with this disaster. This happened because of the Sumatra-Andaman Islands earthquake occurred in Sumatra island. The magnitude of the earthquake has been recorded as 9.1 on the Richter scale. In 2004, almost two-thirds of the Sri Lankan coast were affected by this disaster highlighting the country's vulnerability to low-frequency but high impact events. Coastal districts of Jaffna, Mullativu, Trincomalee, Batticaloa, Ampara, Hambantota, Matara and Galle were highly affected by tsunami disaster. Though it happened 16 years ago, still people are suffering from that disaster because it destroyed everything that belonged to people within few minutes.

A. Problem Statement

Tsunami disaster was the worst natural disaster faced by Sri Lankans. The need of early warning towers had been raised up because of this disaster. After the tsunami disaster in 2004, 77 early warning towers were established all over the country more than 14 years ago. Within this 14 years of period Sri Lanka had not experienced a Tsunami disaster. So, it is very important to check the effectiveness of this Tsunami towers and whether they are adequate or not to the community. In Matara district, 7 Tsunami early warning towers have been established to cover the coastal area. (Matara, Dickwella, Mirissa, Polhena, Naotunna, Weligama and Devinuwara). After the establishment of these early

warning towers, there were many geographical, social changes as well as many other factors have been changed. So, there is a doubt whether these early warning towers have the ability to cover the coastal area or not. Therefore, it is essential to find out whether the current locations of the existing tsunami early warning towers are suitable for locate in existing places when considering about the present conditions.

B. Aim

The main aim of this research is to find the suitability of the existing locations of the Tsunami towers locating in coastal area of Sri Lanka and the ability of the towers to provide the maximum coverage for vulnerable areas in future Tsunami disaster.

C. Objectives

1. To find out whether the strength and coverage of the existing towers are adequated.
2. To identify the factors which affect for a location of a Tsunami early warning tower.
3. To Identify the best Locations for early warning towers according to present context.
4. To conduct a comparison between existing location and proposed location.

Literature Review

There are 77 early warning towers now located in the coastal line of Sri Lanka. According to author's findings, the pre-recorded message with the siren and live voice message cover more than one kilometer from the base of the tower. The message delivers to the public in any disaster situation as an alert, warning, evacuation and withdrawal. Furthermore, it has been mentioned that coverage of these towers depends on the climatic condition and the weather (Jayarathne, 2016). But according to the data gathered from the community, the coverage of these towers depends on the time of the day too. As well as some areas of the coastal line, only hear the siren, and cannot hear the voice message. Here also, it has been taken 1 km as the coverage area of the Tsunami towers.

According to the findings of Wijerathna S., Weligama bay was affected by the Tsunami disaster in 2004 and this caused nearly 400 deaths locally in addition to the destruction of valuable properties. Main objective of this research was to examine how the waves of the Tsunami disaster affected the coastal environment of Weligama Bay area. When finding out the optimum location determination of the Tsunami early warning towers also, damage analysis from the 2004 Tsunami and mapping of the hazardous areas are very important. For this research, author has used ArcGIS software as the main data analysing software. (Wijeratne, 2015)

A researcher has found out the ability to study the problems regard with the locations by using the science of modern GIS software. This was done by providing the input as raw data to display the model results. The most common data formats which were used in GIS can be identified as raster based Digital Elevation Model and the Triangular Irregular Model which are based on the raster models. Researcher further expressed that these two types of data formats are doing a great job at representing a continuous surface and important in solving surface modelling problems. Both of these models give the results which can be easily illustrate in a graphical method in a map on computer screen. (Church, 2002)

A researcher has used LiDAR (Light Detection and Ranging) data sets to create a DEM raster in the research area. Bing

maps were used to identify the data of town features tend to identify the road networks. The buffer zones have made to categorize the zones of multiple towers. Accordingly, the new locations of the towers have been identified by considering slope analysis and the height of each tower. After determination of the locations of the towers, a view shed analysis has been done by the researcher. (BENHAM, 2012)

Wijethunga J.J. has considered about east, south and the west coasts of Sri Lanka as the study area. The Tsunami heights were basically identified by the visually based on the witnesses of the community, watermarks and according to the damages on the structures. Here hand-held Global Positioning System (GPS) was used to obtain the corresponding location in the ground. According to the researcher, the deepest wave height penetrates at Hambantota in the south coast, nearly to a weave with a height of 10m. Researcher has further found that the Tsunami waves had been conveyed to the inland through the water bodies such as lagoons and lakes which are opening to the sea. The composition in the beaches such as sand dunes and steep beaches were identified by the researcher in the southern coastal area. (Wijetunge, 2015)

Methodology

A. Study Area

The research area for this research is coastal line of Matara district from Matara to Dickwella, of southern province in Sri Lanka. This area covers 44km^2. This area was selected inside to the country as nearly 2kms from the coastal line. This 2km distance was selected because the maximum inundation distance towards the inland of the tsunami wave was near to 2kms in some areas of the Matara district. (Wijetunge, 2015)

B. Data Collection

The data that needed for this research was collected from,

- Field visits in the research area
- Disaster Management Center, Sri Lanka
- Survey Department, Sri Lanka
- Census and Statistical department, Sri Lanka
- Interviews held with community in the research area

C. Identification of the current Locations of the Tsunami Towers in between Matara and Dickwella

In this research, CTDroid mobile application was used to locate the points. CTDroid app facilitate visualizing coordinates in WGS84 (World Geodetic System) Kandawala and it allows projected forms and saving waypoints. It works with the aid of GPS receivers in the smartphone which use to run this application. The application allows to examine stored locations, deleting the locations and exporting them in different file formats such as comma separated value (CSV) format, Key hole mark-up language (KML) format and Global Position exchange (GPX) format. This Software was freely available in the google play store for the android devices. (Alahakoon AADC, 2014)

D. Importing Data to ARC GIS 10.3 Software

Arc GIS software was used as the main Software for the Data Analysis in this research. This software can be used to preparae the location maps with the aid of digital data layers. (Piyadasa, 2012)

The geographical locations of the Tsunami towers were exported in to CSV format through the CTDroid software. The coordinate system which used to store these coordinates in CTDroid application was “WGS84 Coordinate system”. The

coordinate system of digital data layers of the research area which was collected from the survey department was stored in the format of "GSC Kandawala" coordinate system.

E. Check the Coverage of the existing Tsunami towers

From the field survey, which was done with the community in the research area, 50 locations were selected out of 200 of sample sizes to confirm that the coverage of this existing Tsunami towers is spreading around 1km or not. The locations of the interviewed points were positioned with the aid of CTDroid software. These points were classified according to community which can hear the early warning siren and community which cannot hear the early warning siren.

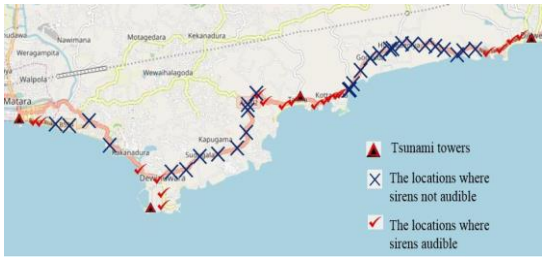

Figure 1. Locations of 4 Tsunami towers and locations of the interviewed points
Source: Survey Department, Sri Lanka

Following figure shows the locations which the Tsunami early warning siren is audible and locations which the siren is not audible.

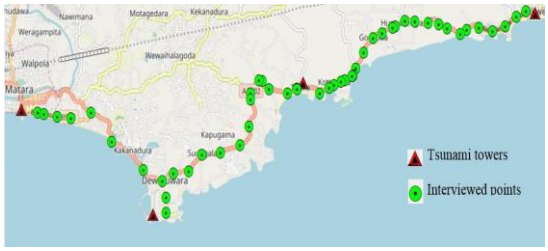

Figure 2. Locations where sirens are Audible and not.
Source: Survey Department, Sri Lanka

F. Determination of Optimum Locations for The Tsunami Warning Tower

Mainly 2 factors can be identified for the determination of the best location for the Tsunami early warning towers.

- What are the areas should cover with the Tsunami towers?
- What are the factors to be concern for the protection of the Tsunami towers?

G. The Elevation and Geographical condition of the areas.

When comparing Matara District with Galle and Hambantota districts in the Southern province, the areas which affected with the Tsunami disaster in December 2004 was comparatively less (Wijetunge, 2015). A Triangulated Irregular Networks (TIN) were developed using Arc GIS 10.3 software to represent the surface morphology in the research area.

Figure 3. The Triangular Irregular Networks (TIN) model which developed for the Research area
Source: Survey Department, Sri Lanka

The light blue color indicates the elevations in between 0-5 meters. The light blue color areas which near to the sea are the most vulnerable areas for a future Tsunami disaster. This area must be covered with Tsunami early warning towers.

H. The areas locate near to the water resources which connect with the sea

According to the research area, there were 5 water resources (Nilwala river and 4 lagoon areas) which connect to the sea that can be identified by the digital data layers of hydrological features.

Figure 4. Areas which have a risk of Tsunami due to water resources which connected with the sea
Source: Survey Department, Sri Lanka

I. The Areas which don't cover with any authorities to warn the people in such incidents like Tsunami

In this research area, 2 police stations have been identified as Gandara and Dickwella. According to the data collected from Disaster management center, they have the capability to send a Tsunami early warning message between 30– 60 minutes for the people around 1 to 2 km area from the police stations before a Tsunami. The police stations have the strength to distribute such kind of a warning message within the coastal area through loud speakers and mega phones. By using 1km buffer area in Arc GIS, the areas which do not cover with police stations have identified as follows.

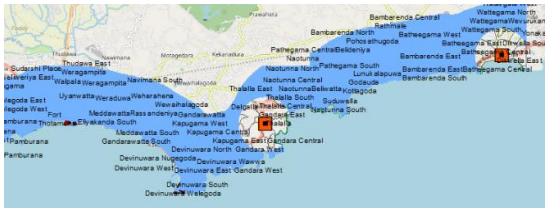

Figure 5. Areas which do not cover with the police stations
Source: Survey Department, Sri Lanka

J. Reasonable distance from the coastal line

The height of the Tsunami wave in December 2004 was differed 3m to 6m in the research area. (Wijetunge, 2015) So the Tsunami towers can be damaged by Tsunami waves. The main important thing is Tsunami is not a single wave. The most vulnerable area for a Tsunami disaster was 100m away from the coastal line. So, it was designed to locate the Tsunami towers 100m away from the coastal line, but not more than 500m away from the coastal line. According to the above conditions, the appropriate area was found using Arc GIS 10.3 software as shown in the figure below.

Results and Discussion

A. Strength and the coverage of the existing towers

Figure 6. Area in between 100m and 500m away from the coastal line
Source: Survey Department, Sri Lanka

According to the GPS coordinates which were obtained by the CT Droid software, current locations of the Tsunami towers were identified, and those locations were represented graphically in the Arc GIS software as shown in the figure below. According to the data collected from the Disaster management center, all these four towers were in working condition.

Figure 7. Locations of 4 Tsunami towers in between Matara and Dickwella
Source: Survey Department, Sri Lanka

3 buffer zones were developed to determine what is the actual coverage area of Tsunami towers in the research area. The 3 buffer zones were selected as 500m, 1000m and 1500m. According to the results, the coverage of the Tsunami towers was taken as 1000m away from the base of the Tsunami towers. Disaster Management Center of Sri Lanka also considered the coverage of the Tsunami early warning towers as 1000m from its base. The areas inside this 1000m buffer zone, can be identified as the areas which are safe from such kind of disasters.

Among the 43 Grama Niladari divisions which affected from the Tsunami disaster, the most important thing was to identify the areas which do not cover with the

current Tsunami towers. The coverage area of the existing Tsunami towers in any time of the day (depend on climatic and weather changes) was represented by 1km buffer area from the base of the tower

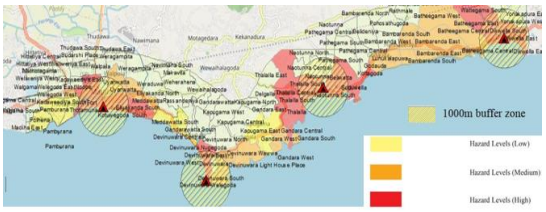

Figure 8. The Coverage area of existing tsunami towers with 1000m buffer area
Source: Survey Department, Sri Lanka

Out of the 43 Grama Niladhari divisions in the research area, 16 Grama Niladhari Divisions were not covered with the current Tsunami towers. So, cannot satisfy with the current coverage of the Tsunami towers in between Matara and Dickwella area.

B. The factors which affect for the location of Tsunami early warning towers

The following factors were identified as the factors which affect for the location of Tsunami early warning towers.

1. Should be located by considering the elevation and geographical condition of the areas.
2. Should cover the land areas which the water resources connect with the sea
3. Should cover the areas which are not covered by the police or any other similar authorities to warn the community in the research area.
4. Should be located after considering distance from the sea. (to minimize the effect of a Tsunami wave on the tower)
5. Should locate in a place with low risk of floods.
6. Should locate near main road network system.
7. Should locate in the most densely populated areas.
8. Should locate near to the evacuation paths.

Above 8 factors were identified by the information gathered from Disaster Management Center and the literature review.

In this research, it was taken only the first five factors according to the Disaster Management Center. Consideration of first five factors is most important to identify the location of the tsunami tower. Here it was considered about the areas which should be covered from the Tsunami early warning towers and the factors which affect for the protection of the Tsunami early warning towers.

According to the information collected from the Disaster Management Center the coastal area in between Matara and Dickwella had not a high risk of floods. So, in this research, it was not considered about the fifth factor when finding the optimum location of Tsunami early warning towers.

C. Identification of the best location for early warning towers according to the present context

The most dangerous areas according to the geographical features of the research area are shown as below.

Figure 9. The Most vulnerable areas according to the Geographical features and the data collected from the respective authorities of the area.
Source: Survey Department, Sri Lanka

The areas around the water features which were connected to the sea also determined as dangerous areas for a future Tsunami disaster. So, the most vulnerable areas with the water resources were shown as following figure.

Figure 10. The Most vulnerable areas in between Matara and Dickwella by considering all the factors.
Source: Survey Department, Sri Lanka

There are 2 police stations located in this research area as Gandara and Dickwella. So, the areas which are not covered by these police stations were identified as in the following figure.

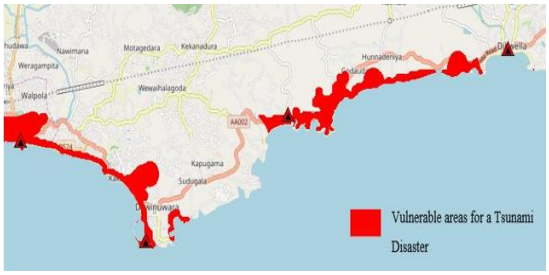

Figure 11. The Most vulnerable areas in between Matara and Dickwella which not covered by police stations
Source: Survey Department, Sri Lanka

To find the optimum locations for the Tsunami early warning towers, the protection and the security of the Tsunami towers also considered. The places where the Tsunami towers can accommodate with the protection and the areas should cover with the early warning towers are shown in the following figure.

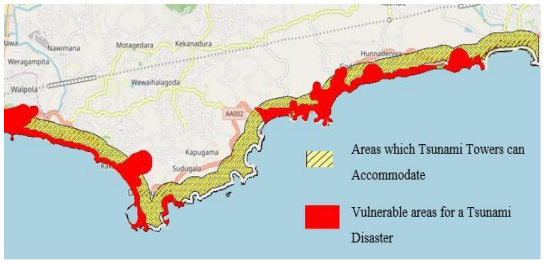

Figure 12. Identification of the areas which Tsunami Towers can accommodate
Source: Survey Department, Sri Lanka

So, to identify the optimum locations for the Tsunami early warning towers in between Matara and Dickwella, the current locations of the Tsunami towers were neglected. The optimum locations for the Tsunami early warning Towers were identified by Buffer tool of the Arc GIS software. A distance of 1000m from the base of the Tsunami towers was used as the coverage of Tsunami towers. The optimum locations of the Tsunami towers were represented graphically as shown in the figure 4.8. According to that, at least 7 early warning towers should be located in the Area between Matara and Dickwella. But there are only 4 towers still located in this area.

Figure 13. Optimum Locations of the Tsunami Early warning Tower
Source: Survey Department, Sri Lanka

D. Comparison of optimum locations and the current locations of the tsunami Early Warning Towers in between Matara and Dickwella.

The graphical representation of the coverage of the proposed early warning towers and the coverage of current Tsunami towers are shown in figure below

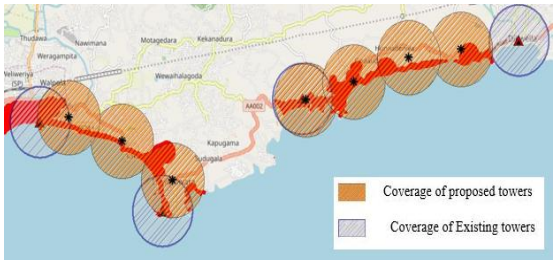

Figure 14. The coverage of the proposed Early warning towers and the coverage of existing Tsunami towers
Source: Survey Department, Sri Lanka

Here the coverage of Tsunami towers in Matara and Naotunna matches with the coverage of the proposed Tsunami towers. But there was a huge difference of the coverages of Devinuwara Tsunami tower and the Dickwella Tsunami tower.

Dickwella Tsunami tower is located inside the police station of Dickwella. Actually, there is no requirement to locate this tower inside a police station. Police has the capability to warn the areas around the police stations rather than a Tsunami Early warning tower. So, if this tower was located in between Batheegama central and the Batheegama east, it will be much better than the current location. Devinuwara tsunami early warning tower is located at the Puranawella area of devinuwara.

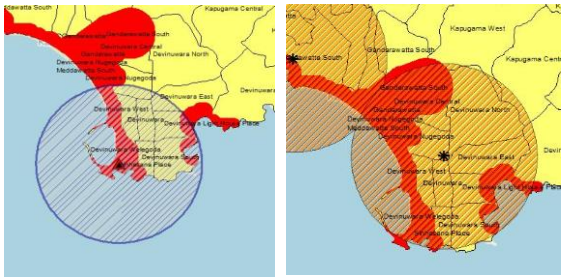

Figure 15. The coverage of the Devinuwara Early warning tower in existing location and proposed location respectively
Source: Survey Department, Sri Lanka

E. The areas do not cover by Tsunami Early Warning Towers or police stations in between Matara and Dickwella.

To identify the areas which are not covered by both early warning towers and Police stations were identified graphically as follows.

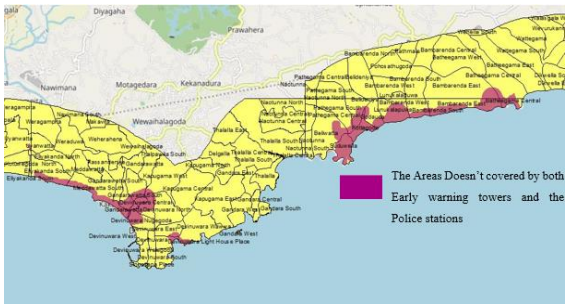

Figure 16. Areas do not cover by both early warning towers and the police stations
Source: Survey Department, Sri Lanka

So, from the figure it can be easily identified there are many areas in between Matara and Dickwella which do not cover with any tsunami tower or police station. These areas were listed according to the DS divisions as follows.

Table 1 The GN divisions Doesn't covered by both Early warning towers and the Police stations

Matara DS division	**Devinuwara DS division**	**Dickwella DS division**
Eliyakanda South	Devinuwara central	Suduwella
Meddawaththa South	Devinuwara Nugegoda	Beliwaththa
	Devinuwara Light house place	Kottagoda
	Devinuwara East	Godauda
		Lunukalapuwa
		Bambarenda East
		Batheegama Central

Source: Author

Conclusion

Field surveys were conducted in the research area to identify the locations and the current conditions of the Tsunami towers. 4 Tsunami towers were identified in the areas of Matara, Devinuwara,

Naotunna and Dickwella. The coverage of the Tsunami towers was mainly determined by the interviews carried with the community of the research area. The further details regarding Tsunami towers and details about the Tsunami affected areas were collected from the Disaster management center and Census and Statistical department Sri Lanka. Arc GIS 10.3 Trial version was used to store data in digital format and further data analysis purposes. The coverage of the Tsunami towers has been depended on the weather and the climatic conditions of the area. From the data collected by interviewing people and data collected from the respective authorities, the coverage of the Tsunami towers was found around 1km from the tower base. From the maps developed with this 1km buffer zone from the base of the Tsunami tower and the data collected from the Census and Statistics department (the most damaged areas from Tsunami disaster 2004), it can conclude that the coverage of the existing 4 Tsunami towers are not enough.

When locating a Tsunami tower, it should consider whether the Tsunami towers could cover the most vulnerable areas as well as the protection of the Tsunami tower. The most vulnerable areas for the Tsunami disaster were identified by considering the geographical features of the research area and the data collected from the Disaster Management Center. Steep beaches in the coastal line of the Matara District was identified as natural protector for a Tsunami disaster. The factors such as the geographical features in the area, the water resources which connect to the sea, the areas which do not have any coverage from police or any other respective authorities and the protection of the Tsunami early warning tower were identified as the factors which affect for the location of the Tsunami early warning tower.

With the analysis of data from the Arc GIS 10.3 software it was found that minimum 7 early warning towers must be located in between the coastal area of Matara and Dickwella area.

According to the current locations of the existing towers of Dickwella and Devinuwara, it cannot be satisfied with the coverage of these 2 Tsunami towers. It was found that these 2 locations to be shifted to Batheegama and Devinuwara East area respectively. If the Devinuwara tower is shifted about 1km to the Devinuwara North from the existing location, it could cover the land areas of 4 more GN divisions which can be affected from a future Tsunami disaster. The existing Dickwella Tsunami tower is in the premises of Dickwella Police. In an emergency, the existing coverage areas of the Dickwella Tsunami tower can be covered by the police too. Same as the Devinuwara early warning tower, if the existing Dickwella tower is shifted to Batheegama area it could cover vulnerable areas of 2 more GN divisions which do not have any protection from Police stations as well as existing Tsunami warning towers.

According to the present situation the vulnerable areas of 13 GN divisions were identified as areas which are not covered with either the Tsunami towers or police stations in this research area. If Devinuwara and Dickwella towers could shift to new locations as mentioned above, the most dangerous areas of these 13 GN divisions could be minimized up to 7 GN divisions.

So following recommendations can apply to increase the number of areas which cover with Tsunami early warnings.

- Implementation of new Tsunami early warning towers for the areas which do not have any protection.
- Inform the community using mobile warning system.

- Practice the community with Tsunami evacuation drills.
- Appoint personnels such as Grama Niladhari in this most risky areas to keep update by early warning messages with respective authorities

In this research, the research area was minimized to the area between Matara and Dickwella in southern coast. So, in future it is very important to identify areas which are not covered with any of the warning system in the other coastal areas in Sri Lanka.

Further, in this research it was found some people in these coastal areas still do not aware about the Tsunami early warning towers. So, it needs to find the methods that can be carried out to make these community to aware about the Tsunami early warning systems.

Acknowledgement

To all staff members of the Faculty of Engineering, General Sir John Kotelawala Defence University for their dedication and effort to get this project success. My Special thank goes to Mr. Pradeep Kodippili, Assistant Director at Disaster Management Center, Sri Lanka, who helped me to carry out this research in numerous ways. Then my gratitude goes to staff members in Disaster Management Center, Survey Department and Department of Census and Statistics for providing me correct details. At last I would like to thank my family members, friends and all others who helped me to stand this project to success.

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Abbreviations and specific symbols

LiDAR - Light Detection and Ranging
DEM - Digtal Elevation Model
GIS – *Geographic Information System*
GPS - Global Positioning System
WGS84 - World Geodetic System
CSV - comma separated value
KML - Key hole mark-up language
GPX - Global Position exchange
TIN - Triangulated Irregular Networks
GN Divisions – Grama Niladhari Divisions

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Paper ID 97

Analysis of the Fire Effectiveness of Medium Calibre Indirect Fire Naval Weapon System

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Abstract: 'Oto Melara' 76/62mm Compact Single Mounting Weapon system is the largest caliber one and only fire control radar coupled weapon system Sri Lanka Navy possessed with by 2019. Yet, this could not effectively used during war time due to prolong defects and its effectiveness also not analyzed by any means we don't follow such a system too. Analysis or the prediction of the effectiveness of a particular weapon system before acquiring and operational use, is an important aspect. This process is mainly based on analysis of all possible static, dynamic error sources and certain environmental parameters related to firing ground, integrated through a calculation model. Single Shot Hit Probability (SSHP) is used in this study for analyzing the fire effectiveness of the said weapon system through a Matlab based calculation model. The model is based on what practiced by PLA Navy (Naval University of Engineering) and considers errors in the Observation equipment, Fire Control, Servo systems, Ballistic Meteorological errors and Dispersion errors for predicting the distribution of shots. SSHP of the system against various targets of large and smaller size kept at various ranges, bearings from the firing ship is considered for the analysis and hitting the target is considered as a kill, due to the effect of the 76mm High Explosive ammunition. Military personnel in the Gunnery field and decision makers would be benefitted with this study by enhancing the knowledge on sources of firing errors and how to predict the effectiveness of a weapon system without choosing the costly method of analyzing actual firing records.

Key Words: Weapon System, Errors, fire Effectiveness

Introduction

Aim of every firing mission is to directly hit the target or to fall the rounds within a specified area that it can Kill or Incapacitate the Target. Even though, first round hitting the target is the most desired condition, it is highly unlikely in actual firing missions even provided with sophisticated systems and executed under controlled conditions.

Projectile leaving from Gun Barrel follows a curved path (Trajectory) due to Earth's Gravitational Pull. Trajectories in the Vacuum and Air; differs due to the presence of Air Resistance in the atmosphere.

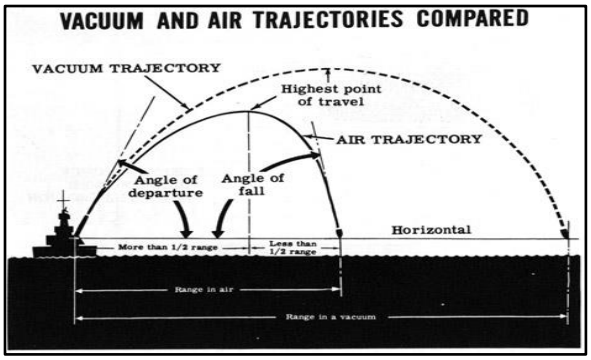

Figure 1: Trajectory of a Gun Projectile in the Vacuum and Air
Source: (United States Naval Academy, 2018)

A. *Naval Firing Process*

Firing process of a shipborne gun weapon system involves many steps followed assuring the desired accuracy under varying conditions. Accordingly, a general procedure for a medium caliber indirect fire gun weapon system is as follows.

i. Initial detection of Targets done by Ship's Search/Surveillance Radars (for Position, Speed)
ii. Target Identification (from available records, EW and target behavior)
iii. Target Acquisition by the Fire Control Radars and/or Optronic Devices (present position)
iv. Target Tracking (obtain Bearing, Range and Speed continuously)
v. Predicting the Target's Future Position
vi. Enter Ballistic Corrections (For changes from Standard Conditions)
vii. Stability corrections for pitching and rolling movements of the ship (using gyro, stable vertical equipment and Fire Control Computer)
viii. Continuous Providing of 'Lead' by the Fire Control System (FCS) with
ix. Provide Gun Laying orders to the mounting (Train and Elevation angles) through Servo System.
x. Firing commenced when target reach the max effective range.
xi. Repeat the process with splash corrections (observing fall of shots)

B. *Standard Shooting Conditions*

Every weapon system is designed and proven best for certain set of conditions called 'Standard Shooting Conditions'. Following are some of the general conditions and firing missions conducted under varying conditions demands corrections refereeing to the Firing Tables made for the particular weapon system.

Weather	Location
Air Temperature	Gun and Target at the same Altitude
Air Density	Accurate Range Obtained
No wind and Rain	Flat Earth Surface and No Rotation

Material

Standard Projectile (weight, shape) and Fuse Status
Standard Propellant Temperature
Leveled Trunnions and Precision Settings (Gun Base)
Standard Muzzle Velocity (as per Firing Table)

C. *Firing Accuracy and Errors*

The standard shooting conditions given for a particular gun weapon system are never met in actual firing environments. These varying conditions; paved the way for firing errors ultimately effecting the desired accuracy. Several Rounds fired from a single gun within a short time under same conditions would follow different Trajectories forming a conical beam. The impacts found to be dispersed on the ground or sea, around a central point; called the Mean Point of Impact (MPI).

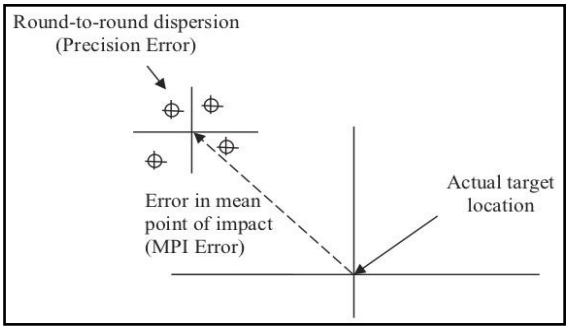

Figure 2. MPI and Precision Errors
Source: (Driels, 2013)

There are various error sources responsible for the fired projectile not hitting the Desired Point of Impact (DPI). All the errors accounted for can be categorized under two errors. They are Precision (Dispersion) and Mean Point of Impact (MPI) errors.

i. *Precision Error*: The precision error is a measure of the dispersion of a group of rounds fired by a single gun about the mean point of impact on a single occasion. The variant qualities of ammunition are mainly responsible for this error.
ii. *Mean-Point-of-Impact (MPI) Error*: The Mean-Point-Of-Impact (MPI) error or the so-called aiming error is a measure of the variability of the mean point of

impact of a single gun, fired at the same target coordinates, over multiple occasions. In a typical weapon system; Observation equipment, Servo System, Fire Control System and Ballistic Meteorological Errors accounts for MPI error.

Firing Errors can be mainly classified as Systematic and Random. Systematic errors are either constant with the time or changes according to a pattern which can calculate and compensated for better results. This further divide as follows.

i. Fixed Biased - Constant errors, Value Not change with the time
ii. Variable Biased - Accumulation errors, Value changes occasion to occasion but follows certain rule (MPI / Aiming errors)

In contrast, Random Error means the values and sign of error changes randomly. (Round to Round Dispersion/Precision errors) where we cannot exactly calculate for compensation. Improving the fire effectiveness of a weapon system needs eliminate or reduce the effect above errors types as depicted in the figure bellow.

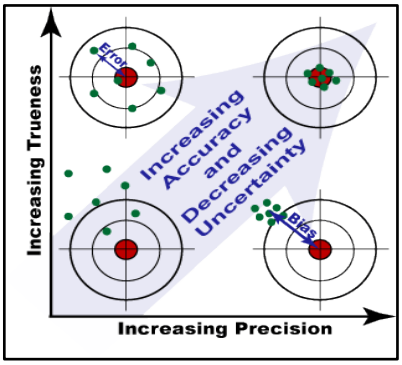

Figure 3: Improving the Firing Accuracy
Source: slideshare.com

D. *Weaponeering*

Weaponeering can be defined as the process of determining the quantity of a specific weapon required to achieve a defined level of target damage, considering target vulnerability, weapon effects, munitions delivery error, damage criteria, probability of kill, weapon reliability, etc. In the operational arena, where planners are striving for the most effective use of limited resources, efficiency is a critical factor that must be considered in the weaponeering process.

The principle mission of the delivery accuracy component of weaponeering is to provide statistics parameters describing the expected error distribution of munitions launched from given conditions against a defined target. In the ideal world, these statistical parameters are obtained from the field and tunnel trials. Practically, however, for many weapon systems this is too expensive to do. So, predictive models are often used for the purpose (Driels 2013).

Problem Statement

Oto Melara 76/62 mm Compact Gun Weapon System (medium caliber indirect fire) installed onboard Fast Missile Vessels (FMVs) was the highest caliber, one and only fire control radar coupled weapon system Sri Lanka Navy (SLN) had by 2019 and This gun is a universally accepted and around 1000 guns are operationally used in the world navies at present yet with different versions. Sri Lanka Navy couldn't use it effectively during the war time mainly due to prolong defects and its effectiveness was never calculated and we don't have such method too. Further, there is not much attention paid on the knowledge and practice of analyzing firing errors in view of improving the fire effectiveness of such of weapon systems.

Figure 4: Oto Melara 76/62 mm Installed Onboard SLN FMVs

Objectives

This study is headed towards three main objectives as follows.

i. To introduce a calculation model for analyzing Fire Effectiveness of an Indirect Fire Naval Weapon System against surface targets.
ii. To Calculate SSHP and Analyze Fire Effectiveness of Oto Melara 76/62 mm Compact Gun Weapon system against various surface target settings.
iii. To influence the future researchers in Sri Lanka to conduct projects for weapon system optimization

Research Design and Methodology

A. *Fire Effectiveness Analysis*

To assess the effectiveness of a ship borne gun against surface (sea) targets, the performance of the total weapon system has to be considered. Hence, we need to determine the effectiveness on the basis of performance of the following factors.

i. Manually or automatically (servo) trained guns
ii. Visually identification of the aim point or sensor driven (radar/thermal)
iii. Engagement range
iv. Fire Control System capability to provide 'Lead'
v. Stabilized or Unestablished ship motion

Whilst various factors affecting the Firing Accuracy, the observable outcome is the deviation of shots from the target Or the Desired Point of Impact (DPI); in Range and Deflection. Therefore, we should find or predict the amount of deviation from DPI to determine the accuracy and subsequently the fire effectiveness of the system. A model is an implementation of a methodology, that is, a practical way to obtain a result such as Pk (likelihood of killing) or Hitting (P_h) (Driels, 2013). There are many fire effectiveness calculation methodologies and models used in the present-day world which evaluates; Effects of Target and Shooter motions, Accuracy of Aiming the Gun, Projectile Trajectory, Target Vulnerability, Effectiveness of the Warhead against the Target, as follows.

1) Statistics and Test Method: Obtain large amount of test firing records and then calculate error probability. This is costly.
2) Statistics and Simulation Method: more famous and effectively used with varies models with the help of programming languages and tools like Monti Carlo, Simula, GPSS suited to particular weapon system (Sherif and Kheir 1981). Such models designed to simulate engagement between a surface ship mounted gun and surface targets and method demands use of costly software.
3) Mathematical Analysis Method: Formulas are developed for the firing process included all possible errors and accordingly predict the probable miss distance from the DPI with mathematical expectation. Then, analyze error with the target parameters to find out whether it is a hit or miss. This method is used for analyzing of fire effectiveness in this study considering it can avoid the long time needed to determine statistics using iterative techniques like Monti Carlo.

This predictive method of mathematical analysis uses the Expected Value theorem for computation of fire effectiveness. Expected Value can be considered as the mean value of a function E(x) would take for a large number of independent random selections of 'x' as expressed bellow (Driels 2013).

$$E(x) = \sum_{i=1}^{i=n} xiP(x = xi) \quad (1)$$

This study calculates the Single Shot Hit Probability (SSHP) for various target parameters and conditions through a calculation model prepared by identified firing errors taking into account. Subsequently the fire effectiveness is analyzed.

Designing the Model

Fall of shots around MPI are recorded as Miss Distances in Range (x) and Deflection (z). x and z are independent variables. Fall of rounds fired from a naval weapon system considered to follow the Bivariate Normal Distribution with an Elliptical base representing the area of dispersion (Driels, 2013).

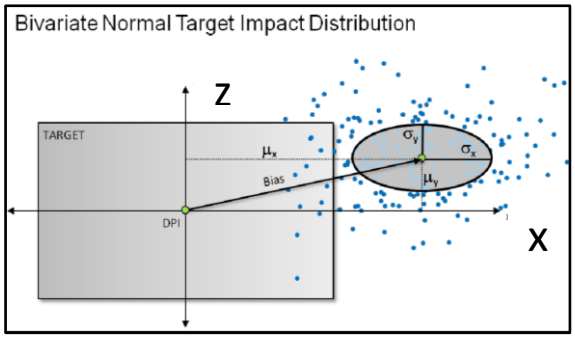

Figure 5: Bivariate Normal Impact Distribution of Shots
Source: (Driels, 2013)

Probability Density Function (PDF) of distribution of shots on the coordinate (x, z) as used in most Weaponeering methods can be expressed as follows (Driels, 2013).

$$f\ (x,y)\ =\ \frac{1}{2\pi\sigma_x\sigma_y}\ exp\ -[\frac{(x-\mu_x)^2}{2\sigma_x^2}\ +\ \frac{(y-\mu_y)^2}{2\sigma_y^2}\ ] \quad (2)$$

In the above equation, $\boldsymbol{\mu_x}$ and $\boldsymbol{\mu_y}$ are 'Means' of shot distribution along each axis. $\boldsymbol{\sigma_x}$ and $\boldsymbol{\sigma_y}$ are standard deviations or the Mean Square Deviations. According to our problem, the Single Shot Hit Probability (SSHP) against a rectangular target, P(x, z) is obtained by formula 3. And It is further expanded in formula 4.

$$P(x,z)\ =\ \iint_{\substack{x\in(-lx,\ lx)\\ z\in(-lz,\ lz)}} f(x,z)dxdz$$

$$=\ \int_{-lx}^{lx} f(x)dx\ \int_{-lz}^{lz} f(z) \quad (3)$$

$$P(x,z)=\ \iint_{\substack{x\in(-lx,\ lx)\\ z\in(-lz,\ lz)}} \frac{1}{2\pi\sigma_x\sigma_y}\ exp\ -[\frac{(x-\mu_x)^2}{2\sigma_x^2}\ +\ \frac{(y-\mu_y)^2}{2\sigma_y^2}\ ]\ dxdz \quad (4)$$

Here the. $\boldsymbol{lx}$, $\boldsymbol{and}$ $\boldsymbol{lz}$ denotes length and width of a Rectangular target. $\boldsymbol{\mu_x}$ and $\boldsymbol{\mu_z}$ can be considered as zero for this case, as there is no'Mean' for such shot distribution on x, z plane (Xing Changfeng, 2007).

Matlab based calculation model for Single Shot Hit Probability (SSHP) for a surface to sea target can be formed in the Laplace form as follows.

$$P(x,y)=\frac{1}{4}[\phi(\frac{mx+lx}{\sqrt{2}\,\sigma x})-\phi(\frac{mx-lx}{\sqrt{2}\,\sigma x})].[\phi(\frac{mz+lz}{\sqrt{2}\,\sigma z})-\phi(\frac{mz-lz}{\sqrt{2}\,\sigma z}) \quad (5)$$

Then, the single shot hit probability can be represented as,

$$P(x,y)=\frac{1}{4}[\bar{\phi}(x_1)-\bar{\phi}(x_2)].[\bar{\phi}(x_3)-\bar{\phi}(x_4)] \quad (6)$$

In this equation,

$x_1=\frac{mx+lx}{\sqrt{2}\,\sigma x}$; $x_2=\frac{mx-lx}{\sqrt{2}\,\sigma x}$; $x_3=\frac{mz+lz}{\sqrt{2}\,\sigma z}$; $x_4=\frac{mz-lz}{\sqrt{2}\,\sigma z}$
(Xing Changfeng 2007)

A. *Coordinate System*

A coordinate system is introduced as depicted in the following figure to best understand the Single Shot Hit Probability (SSHP) calculation method used in this study.

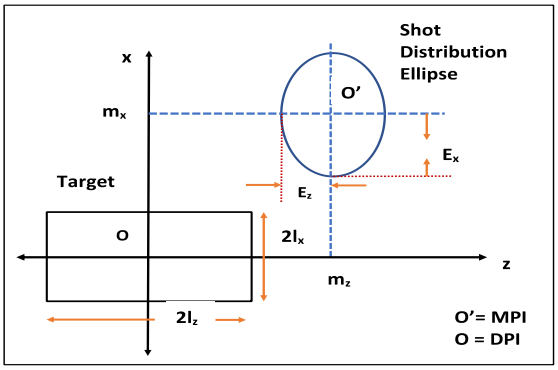

Figure 6: Coordinate System Designed for Analyzing the Hit Probability

The Ellipse formed with the center 'O' as per above figure, represents the Base of the Bivariate Normal Distribution. 2lx and 2lz are target width and length respectively. m_x, m_z are overall systematic errors. Once the Ellipse touches the Rectangle means a successful Hit.

Single Shot Hit Probability (SSHP) Calculation Model for 76/62mm Compact Gun Mounting Weapon System

Here, the Single Shot Hit Probability (SSHP) considered as the measurement for fire effectiveness calculation and analysis of the subject weapon system. SSHP is assumed to be similar to Probability of Kill (Pk) due to this study is mainly focused on effectiveness against small attack craft and suicide boats which a single hit with impact detonating projectile would incapacitate the target. Computation method for analyzing the fire effectiveness of Oto Melara 76/62mm Compact Mounting Weapon System against steady surface (sea) targets introduced following errors (Xing Changfeng 2007).

i. Dispersion Error
ii. Shooting Errors (MPI)
    a. Servo System error
    b. Fire Control error
    c. Observation error
    d. Ballistic Meteorological error

A. *Calculation Model for Precision Errors*

The precision (dispersion) error values of parallel and cross (range and deflection) for maximum range is given in the particular firing table. These values can be adjucted/estimated using following equations for a given range (Lim 2016).

Parallel≤1/180m(for range), Ex(pre)=dp/180 (7)

Cross ≤1 mil(for deflection),Ez(pre)=1*dp/955 (8)

Here the Deflection error to be converted from mil to meter and done by multiplying 1/955. The 'dp' is the Target range.

B. *Calculation Model for MPI Errors*

1) Calculation of the Servo System Error: Due to the transmission error of the ship gun follow up system, the actual firing of the naval gun and the fire control solution for the predicted point of the target can be different. This difference is the servo system error. It includes the Direction (Training) tracking aiming error ($\Delta\beta_m$) and the Range (elevation) tracking aiming error ($\Delta\varphi_m$).

i. Calculation of Probability of Tracking Error in Direction (Ezm)
   $Ezm = Cm. .dp .E\beta m$ (m) (9)
ii. Calculation of Probability of Range Tracking Error at the Predicted Point (Edm)
   $Edm = fd\theta . E\varphi m$ (m) (10)

Note:

Here, the $Cm = 2\pi/6000 = 1/955$ (coefficient for converting Radian to Mills), $fd\theta$ is the range change coefficient caused by the change of elevation angle. It is a constant, $fd\theta = 67.71m$. $E\beta m = E\varphi m = 4$ (mil) Known Error Probabilities (system)

2) Calculation of Observation Equipment Error: Observation equipment includes the Radar and the Optical Range Finder. Observation equipment measurement error refers to the deviation of the measured target position parameter values through the observation device from the actual target position parameter values. This includes the target range and direction errors as follows.

i. Observation equipment ranging mean squared error (Laser $Range\ finder-\sigma_{dg}$, Radar - σ_{gd}) and the respective systematic errors, m_{dg} and m_{gd} are:

   $\boldsymbol{\sigma}_{dg} = \boldsymbol{\sigma}_{gd}$(m) (11)
   $m_{dg} = m_{gd}$ (m) (12)

ii. Mean square error in direction for given target range: $\boldsymbol{\sigma}$zg and the systematic azimuth error caused by the observation equipment, mzg can be found by:

   $\boldsymbol{\sigma}_{zg}$ = **C**m.dp. $\boldsymbol{\sigma}_{gq}$(m) (13)
   m_{zg} =Cm. dp. $\boldsymbol{m}_{gq}$(m) (14)

σ_{gq} - Direction measuring MSE of EOD is known as 1.6 mil
m_{gq} - EOD System Direction measuring error is known be 1.6 mil

3) *Calculation of Fire Control Error*:Fire Control error of the Gun director includes both System Error and Random Errors. In this case, the System Error $m\boldsymbol{\beta}_c = m\boldsymbol{\varphi}c$ and the Random Error $E\boldsymbol{\beta}_c = E\boldsymbol{\varphi}_c$.

$\Delta\varphi c$, the range tracking error causes the range error Δdc and the Probability error $E\boldsymbol{d}c$ and mathematical expectation m_{dc}.

$$E\boldsymbol{d}c = \int d\theta . E\boldsymbol{\varphi}_c \quad (15)$$
$$m_{dc} = \int d\theta . m\boldsymbol{\varphi}_c \quad (16)$$

$\Delta\boldsymbol{\beta}_c$, the direction tracking error causes the direction error Δz_c, the probability error $E\boldsymbol{z}_c$ and the mathematical expectation mzc.

$$E\boldsymbol{z}_c = Cm . dp . E\boldsymbol{\beta}_c \quad (17)$$
$$mz_c = Cm . dp . m\boldsymbol{\beta}_c \quad (18)$$

4) *Calculation of Ballistic Meteorological Error:*

i. *Error Caused by Muzzle Velocity Deviation:*When firing to sea targets from a surface ship, the muzzle velocity deviation $\Delta\boldsymbol{V_0}$ is possible due to variations in ammunitions provided and cause the distance (range) error $\Delta\boldsymbol{d_{V_0}}$. Its Probability error at the predicted point (Edv0) can be calculated by,

$$Edv_0 = 0.1 \int d_{V0} . E_{V0} \quad (19)$$

∫dV0 - The Range Change coefficient caused by the muzzle velocity. Change of distance in meters when initial velocity V0 change by 1%. EV0 - Probability Error of the Initial Velocity.

ii. *Error Caused by the Air Density Deviation*: When fire to surface, the air density deviation $\Delta\boldsymbol{\rho}$ just cause the distance error $\Delta\boldsymbol{d\rho}$. Its probability error $E\boldsymbol{d\rho}$, can be calculated by,

$$E\boldsymbol{d\rho} = 0.1 \int dp . E\boldsymbol{\rho} \quad (20)$$

∫dp - The range change coefficient caused by the change of air density, ∫dp = Range change in mtr when $\boldsymbol{\rho}$ change by 10% , $E\boldsymbol{\rho}$ – Probable Air Density Error.

iii. *Error Caused by Ballistic Wind Deviation*: Error caused by Ballistic wind deviation can be divided in to vertical wind error $\Delta\boldsymbol{W}_d$, and Horizontal wind error $\Delta\boldsymbol{W}_z$ .When fire to surface, $\Delta\boldsymbol{W}_d$, causes the distance error, $\Delta\boldsymbol{d}_w$ at the predicted point. Its probability error $E\boldsymbol{d}_w$, can be calculated using following equation.

$$E\boldsymbol{d}_w = 0.1 \int d_w . EW_d \quad (21)$$

$\int d_w$ – The Range change coefficient when vertical wind is 10ms-1
EW_d – Probability of Vertical Wind error (changing amount), EW_d is normally, 2 ~4 (m/s).

Horizontal wind error $\Delta\boldsymbol{W}_z$, will cause the direction error $\Delta\boldsymbol{Z}_w$ at the predicted point. Its probability error Ez_w can be calculated by,

$$Ez_w = 0.1 Cm . dp . \int z_w . Ew_z (m) \quad (22)$$

∫zw -The direction change coefficient when horizontal wind is $10ms^{-1}$, Ewz - Probability of Horizontal Wind error (Xing Changfeng, 2007).

C. *Error Combination*

Dispersion and Aiming errors are combined using Root Sum Square (RSS) method.

$$\mathbf{RSS}= \sqrt{(\boldsymbol{x^2}_1 + \boldsymbol{x^2}_2 + \cdots + \boldsymbol{x^2}_n)} \quad (23)$$

Hence, the calculation model:

$$\boldsymbol{a}_\Sigma\boldsymbol{a}_\Sigma = (\sum_{i=1}^{n} \boldsymbol{a}_i{}^2)^{1/2} \quad (24)$$

Conversion of Error probabilities; Ex and Ey to MSE is done through,

$$Ex = \rho \sqrt{2}\sigma_x \quad (25)$$

'ρ' means the transformation coefficient and equal to 0.4769 (Xing Changfeng, 2007).

Analysis of the Fire Effectiveness against Surface Targets

Analysis of the fire effectiveness of the Oto Melara 76/62mm Compact Mounting

Weapon System has been carried out using above model and applying various conditions for targets of LTTE's Suicide craft and attack craft to denote change of target length, width and height. Target range, Relative Bearing and Falling Angle of the Projectile will be changed one at a time for SSHP calculation for each target type.

A. *Single Shot Hit Probability Against Attack Craft*

1) *Probability Change with Target Range*:

Table 1- Probability Change with Target Range

Sr. No	Target Range (m)	Tgt Relative Brg (Qm)	Falling Angle (Deg)	Tgt Size (m^3)	Effective Tgt Area A_j	Single Shot Hit Probability
1	500	170	60	12x3x3	26.57015	0.00243152
2	1000	170	60	12x3x3	26.57013	0.00123152
3	1500	170	60	12x3x3	26.57013	0.0008229
4	2000	170	60	12x3x3	26.57013	0.00061774
5	2500	170	60	12x3x3	26.57013	0.00049437
6	3000	170	60	12x3x3	26.57013	0.00041205
7	3500	170	60	12x3x3	26.57013	0.00035321
8	4000	170	60	12x3x3	26.57013	0.00030907
9	4500	170	60	12x3x3	26.57013	0.00027473
10	5000	170	60	12x3x3	26.57013	0.00024726

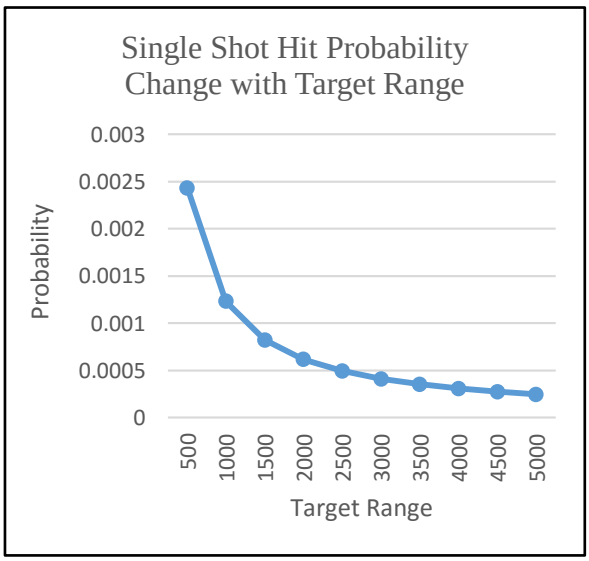

Figure 7: Single Shot Hit Probability Change with Target Range

It is observed that the probability is significantly changed (decreased) with the increase of range up to 1500m and then the rate of change of probability is constant.

2) *Probability Change with Target Relative Bearing*:

Table 2 - Probability Change with Target Relative Bearing

Sr. No	Target Range (m)	Tgt Relative Brg (Qm)	Falling Angle (Deg)	Tgt Size (m^3)	Effective Tgt Area A_j	Single Shot Hit Probability
1	2000	000	60	5x1.5x1	6.866025	0.00015957
2	2000	015	60	5x1.5x1	7.434233	0.00017233
3	2000	030	60	5x1.5x1	7.904700	0.00018268
4	2000	045	60	5x1.5x1	8.245365	0.00019003
5	2000	060	60	5x1.5x1	8.433012	0.00019402
6	2000	075	60	5x1.5x1	8.454854	0.00019448
7	2000	090	60	5x1.5x1	8.309401	0.00019139
8	2000	105	60	5x1.5x1	8.006566	0.00018489
9	2000	120	60	5x1.5x1	7.566987	0.00017527
10	2000	135	60	5x1.5x1	7.020620	0.00016307
11	2000	150	60	5x1.5x1	6.404700	0.00014902
12	2000	165	60	5x1.5x1	5.761200	0.00013407
13	2000	180	60	5x1.5x1	5.133974	0.00011931

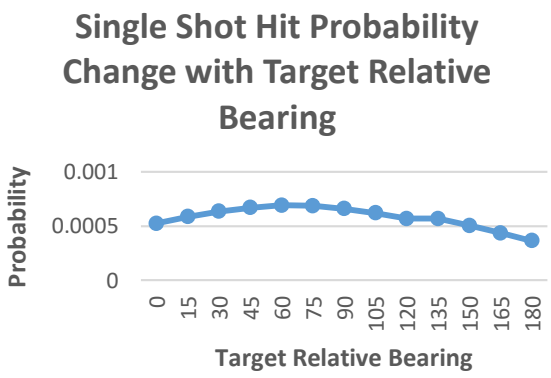

Figure 8: Single Shot Hit Probability Change with Target Relative Bearing

Results of the calculation denotes that the probability of single shot hit the target and therefore fire effectiveness is highest when the target relative bearing is 060^0 in respect to other conditions as indicated above.

3) *Probability Change with Falling Angle:* Next, the Falling angle changed from the 000 degrees to 090 degrees whilst keeping other parameters constant as per the table below for calculation of Single Shot Hit Probability.

Table 4 - Hit Probability Change Pattern with Falling Angle

Sr. No	Target Range (m)	Tgt Relative Brg (Qm)	Falling Angle (Deg)	Tgt Size (m^3)	Effective Tgt Area A_j	Single Shot Hit Probability
1	3000	060	000	12x3x3	Inf	NaN
2	3000	060	015	12x3x3	138.6772	0.00209295
3	3000	060	030	12x3x3	79.79422	0.00120428
4	3000	060	045	12x3x3	58.24153	0.00087900
5	3000	060	060	12x3x3	45.79807	0.00069120
6	3000	060	075	12x3x3	36.68883	0.00055372
7	3000	060	090	12x3x3	28.80000	0.00043466

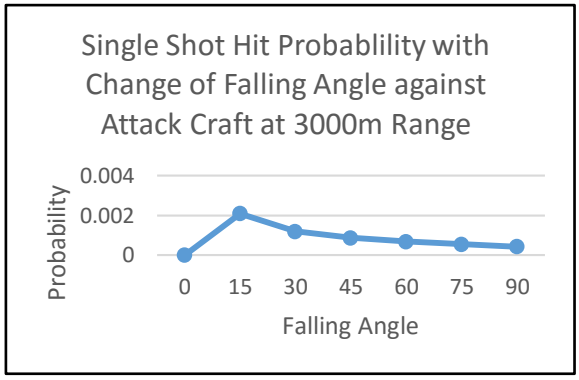

Figure 9: Probability Change with Falling Angle

Single shot hit probability is maximum when the falling angle is 15^0 subjected to other conditions as indicated above. Therefore, it is best to set/arrange falling angle to that amount when designing the ammunition and weapon system.

B. *Single Shot Hit Probability Against Suicide Craft*

1) *Probability Change with the Range*:

Table 5 - Probability Change with the Range

Sr. No	Target Range (m)	Tgt Relative Brg (Qm)	Falling Angle (Deg)	Tgt Size (m^2)	Effective Tgt Area A_i	Single Shot Hit Probability
1	400	090	60	5x1.5x1	8.309401	0.00076385
2	800	090	60	5x1.5x1	8.309401	0.00045367
3	1200	090	60	5x1.5x1	8.309401	0.00031322
4	1600	090	60	5x1.5x1	8.309401	0.00023786
5	2000	090	60	5x1.5x1	8.309401	0.00019139
6	2400	090	60	5x1.5x1	8.309401	0.00016000
7	2800	090	60	5x1.5x1	8.309401	0.00013740
8	3200	090	60	5x1.5x1	8.309401	0.00012037
9	3600	090	60	5x1.5x1	8.309401	0.00010708
10	4000	090	60	5x1.5x1	8.309401	0.00009643

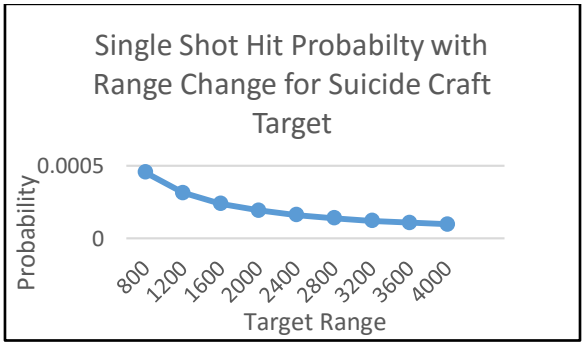

Figure 10: Single Shot Hit Probabilty with Range Change for Suicide Craft Target

It is observed a drastic change (decrease) of hit probability with increase of range. Single shot hit is not assured even with a closer range of 400m for suicide craft.

2) *Probability Change with the Target Relative Bearing*:

Table 6. Probability Change with the Target Relative Bearing

Sr. No	Target Range (m)	Tgt Relative Brg (Qm)	Falling Angle (Deg)	Tgt Size (m^3)	Effective Tgt Area A_j	Single Shot Hit Probability
1	2000	000	60	5x1.5x1	6.866025	0.00015957
2	2000	015	60	5x1.5x1	7.434233	0.00017233
3	2000	030	60	5x1.5x1	7.904700	0.00018268
4	2000	045	60	5x1.5x1	8.245365	0.00019003
5	2000	060	60	5x1.5x1	8.433012	0.00019402
6	2000	075	60	5x1.5x1	8.454854	0.00019448
7	2000	090	60	5x1.5x1	8.309401	0.00019139
8	2000	105	60	5x1.5x1	8.006566	0.00018489
9	2000	120	60	5x1.5x1	7.566987	0.00017527
10	2000	135	60	5x1.5x1	7.020620	0.00016307
11	2000	150	60	5x1.5x1	6.404700	0.00014902
12	2000	165	60	5x1.5x1	5.761200	0.00013407
13	2000	180	60	5x1.5x1	5.133974	0.00011931

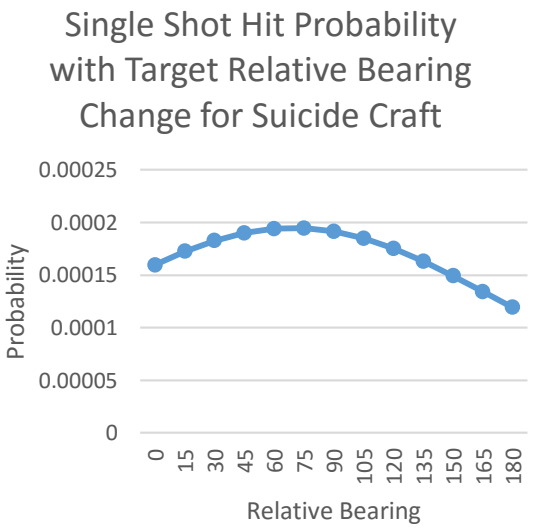

Figure 11: Single Shot Hit Probabilty with Relative Bearing for Suicide Craft Target

When the Target Relative Bearing is reaching 75^0, the single shot hit probability observed to be the highest against Suicide Craft concerned at a range of 2000m.

Conclusion

Choice of suitable method for calculating and analyzing the fire effectiveness of a weapon system, out of various methods available is depend upon the amount of accuracy needed to achieve, how fast it needs to compute results and availability of parameters, weapon system and target data. In view of fire effectiveness calculation, first you have to identify sources of all errors. Not only the Gun's accuracy but also the errors of weapon sub systems like servo, observation equipment, FCS and meteorological /environmental also to be considered. This study aimed to choose a suitable mathematical model and analyze the fire effectiveness of OTO Melara 76mm/62 Compact Mounting Weapon System with reference PLA (Chinese) Navy's practice (Xing Changfeng 2007).

Hit Probability is largely depended upon target range. Hit area of the target is a crucial factor and that is decided by the angle of attack (Rel. Brg) and the angle of fall. There is a pattern of SSHP change related to Target Range, Relative Bearing and the Falling Angle of the Projectile. Knowing that, is beneficial before planning any firing mission. It is important to know the inherent errors of the associated systems and due consideration should be given for mechanical errors and equipment alignment. Accuracy of MET

message is very important factor especially in long range firing. Better to have systems to obtain real time weather parameters.

Following issues found with this Study.

i. Firing Table data, probable equipment errors are from other sources (PLA Navy) due to none availability same under SLN.
ii. Status of both Firing platform and target moving was not considered.
iii. No impact records or Proving ground/laboratory test records available for comparison.

Recommendations for Future Researchers

This can be taken as just a basement and researchers in the Gunnery field (specially Sri Lanka Navy) can try for following works.

i. Design a Matlab based calculation model for similar weapon system to analyze fire effectiveness against fast moving and air targets as it induced some additional error sources.
ii. Design a Computer based programme for simulating the Gun Projectile Trajectory

Acknowledgement

Apart from the efforts of own, the success of any research depends largely on the encouragement and guidelines of many others. I take this opportunity to express my gratitude to all of those who provided me the possibility to complete this research. I would like to express my highest appreciation to all the lecturers of the Naval University of Engineering (NUE), Wuhan, PRC China for the support, encouragement and opening the path for me to conduct such a study.

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Author Biography

The author is specialized in Naval Gunnery in India with award of the best International Student officer in year 2015. Afterwards he had the opportunity to follow a Gunnery Engineering course in PRC China which would emensely benifited in enhancing the knowledge on Naval Weapon Systems. During this course Author again awarded as the Excelent Trainee of the course with a value addition of Master of Engineering degree (MEng) in Naval Weapon Science and Technology completed in year 2019

Paper ID 108

Design of a Wind Propelled Planning Hull Craft for Shallow Water Operation

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Abstract: During recent flash floods, Sri Lanka Navy rescue teams met with many circumstances where they could not use their Dinghies even with a short tail Out Board Motors (OBM) due to submerged obstacles at unprecedented depths. Therefore, designing a planing craft with rescue capability deemed a national necessity. This study explains the designing of a wind powered planing hull craft to operate in shallow waters during natural calamities like flood situations to move where stagnant water masses with uncertainly small depths. A speed boat with performance such as gaining top speed, achieving acceleration timing, turning characteristics, course keeping ability at top speeds, etc. are quite challenging which measure the overall performance of the boat. Preliminary analysis on the issue was made by the naval engineers who were attached to Sri Lanka Navy (SLN), where the case study was done collecting data after series of visits to flood affected areas. Size of the common alleyways in flood affected areas and their general flood height and the depths were calculated and hence size of the required boat with maximum allowable draft has been determined. Since the lesser capabilities of the SLN to finish a hull with required hydrostatic data seems costly a hull with required features determined and purchased to match with a suitable engine and a wind propeller with a suitable steering and protection mechanisms. Therefore, the purpose of this exploration was defined, then researched and designed a light weight flat bottom Fiberglass hull craft propelled by air for carrying out rescue missions during floods. Finally, subsequent study was conducted of hydrostatic and hydrodynamic forces, position of centre of gravity (CG), engine matching and propeller matching to the hull. The newly designed airboat is distinctive, and it can be operated at a wide range of both steady and moving waters.

Keywords: Air-boat, Sri Lanka Navy, Out Board Motors, Offshore Petrol Vessels, Centre of Gravity.

Introduction

In recent years, airboats have been proven that they are capable to handle floods, shallow water operations, and ice rescue tasks, in effectively and efficiently. Consequently, they have fully-fledged with safety practices and developed the reputation among public. History is evident that the flooding was taken place in New Orleans following Hurricane Katrina, on 29th August 2005, and how airboats were effectively utilized to rescue thousands of flood victims. Further, thirty airboats were deployed to evacuate more than 3,000 patients and medical staff from four downtown New Orleans hospitals in less 2 days (Colten, et. al., 2006).

In Sri Lankan context, it was experienced that the flash floods swept across western region of the country in two occasions during the year 2016 and 2017, which crippled the day today livelihood of the general public in flooded impacted areas. Further, reaching to victims of the havoc and survivors with accessible means was the enormous encumbrance confronted by the Sri Lanka Navy (SLN). Subsequently, the nation had to

pursue assistance from neighbor countries to carry out search and rescue operations, to safe guard the victims.

SLN is a rational and unified force, that performs duties on waters around the island effectively and defence national interests. Further, a mission of SLN is very clear and conduct prompt and sustainable combat operations and rescue missions at sea in accordance with the national policies. Moreover, SLN was starting its fleet from smallest fiber glass dinghies, which deployed mainly in inland waters and harbor protections. Subsequently, an introducing Offshore Petrol Vessels (OPV) to the SLN fleet and deployed in blue and green waters as the first line of defence (De Silva-Ranasinghe, 2009).

Numerous forms of rescue boats be existent to navigate over flooded water. An airboat is the best example of such a rescue craft with multiple usage. Normally, these flat bottom-hulled airboats are driven by fans, with utilization of air flow. Further, this water crafts are comparatively compact and able to maneuver in shallow water conditions. Moreover, a hull of this rescue boat is made-up by either aluminum or fiberglass materials (Leppek, 2012). Both aluminum and fiberglass hulled airboats can be effectively used in low-water conditions, compare to 'Out Board Motors' (OBM) driven watercraft. Though, several drawbacks are identified in these airboats operations. Specially in open waters, these types of airboats are extremely difficult operate, if currents, waves or windy conditions developed (Giassi and Maisonneuve, 2004).

SLN had experienced that the rescue teams met with many circumstances where they could not use their Dinghies even with a short tail OBM due to submerged obstacles at unprecedented depths. Therefore, primary analysis on the issue was investigated by the naval engineers who were responsible to research and development of the Sri Lanka Navy (SLN), where the case study was done collecting data after series of visits to flood affected areas. Size of the common alleyways in flood affected areas and their general flood height and the depths were calculated and hence size of the required boat with maximum allowable draft has been determined. Since the lesser capabilities of the SLN to finish a hull with required hydrostatic data seems costly a hull with required features determined and purchased to match with a suitable engine and a wind propeller with a suitable steering and protection mechanisms. Finally, SLN engineers were identified and decided that the designing a planing craft with rescue capability deemed a national necessity. Therefore, the purpose of this exploration was defined, then researched and designed a light weight flat bottom fiber glass hull craft propelled by air for carrying out rescue missions during floods.

Methodology

Material Selection and Design of Hull - Fiberglass was chosen to make this airboat hull due to low cost and the availability of infrastructure facilities related to fiber works at SLN premises. Thickness and type of the hull were decided based on the criteria such as the terrain on which the airboat will be used, total weight of cargo, passengers, and size of the airboat. The flat bottom hull was selected for this airboat while considering rescue tasks and easy handling during floods (Giassi and Maisonneuve, 2004).

According to preliminary design, construction of the airboat was begun with the fabrication of a hull in figure 1. The polyester was selected as the suitable material to construct the hull due to low cost, light weight and minimal elongations. Further, this fiberglass material is directly affecting for the reduction of a friction against rubbing surface of the hull, and improved fuel efficiency. Since the weight factor of the airboat is one of the very

important criterion in this design, weight of the boat was maintained essentially less than 350 kg to fulfil the requirement of easy handling during floods.

The length of the boat is restricted to 12' 10" and maximum breadth is curtailed with 7'. The height is 1' 08" with both sides angled out, at an angle determined from the difference in the beam and bottom widths of the hull in figure 2. Fabricating a transom is vital, and considered as the back panel of an airboats hull. Consequently, the angled sides are generating additional depth to the hull and an increase in the displacement. Therefore, it leads to improve the capacity of the airboat which can carry more number of passengers. In this hull depth changing process, the center of gravity is shifting to rear side of the airboat and set up more stable conditions. A maximum transom is 20" and maximum depth of nose is 16", in this hull design and provide sufficient elevation of the bow above waterline for safe passage. Further, it allows adequate clearance in the situation where the airboat would encounter rough or choppy water that could potentially come over the bow (Tinkham, and Tinkham Sherman, 1977).

Salient features of air boat

Length	- 12' 10"
Max Breadth	- 7'
Height	- 1' 08"
Total weight	- 350 kg
Cage Diameter	- 5' 08"
No of persons	- 02
No of rudders	- 02
Rudder angle Max	- 60º
Speed	- 17 knots (Approx.)
Air propeller Diameter	- 134 cm
No of blades	- 03
Loading capacity	- 150 Kg

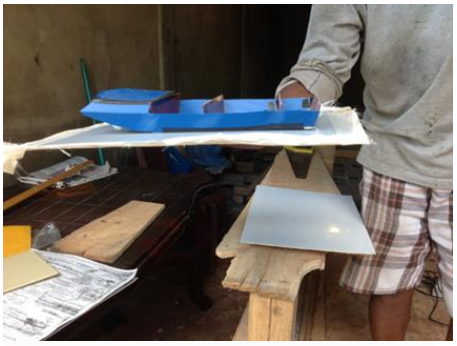

Figure 1: Scaled Down Fiberglass Hull

Figure 2: Fiberglass Hull

Propulsion System - A propulsion system is consisted of an engine, propeller, and rudders. Many options are available to select suitable engines for design airboat. Both aircraft and automotive engines are generally used for airboats, to achieve design speeds. The rotations per minute (rpm) is the major parameter that specified by the airboat propeller manufacturers to select the suitable propeller for airboat. Further, the size, shape and martial of propeller are the key factors for achieving maximum rpm during airboat operations. Aircraft engines generally operate at rpm of 3,000 or lower. Therefore, a less horse power compatible aircraft engine and three blades Carbone fiber propeller is matched and fixed with this airboat to accomplish, the assign task by SLN in figure 3 (Fritsch and Diehl, 1926).

Engine Specifications

Engine HP	- 35 HP
Engine weight	- 45Kg
Engine RPM (Idle)	- 1200
Engine RPM (Max)	- 3600

Figure 3: Engine mounted to the airboat

Seating Arrangement - This airboat was designed to carry one passenger and the operator. The operator's seat is in back, and elevated above the passenger. In addition, it was centered widthwise, therefore that the center of gravity in the widthwise direction is on the centerline of the hull which maintain the stability of the boat. An all-round visibility of the driver is very important during close proximity operation, therefore, the driver's seat is located in little elevated position compare to passenger seat. Further, another mandatary requirement is to position the seat that minimizes the length of the cables for the throttle and clutch. Consequently, it is reducing shifter and rudders connecting linkage length. A drivers seating framework was constructed out of steel composite material with fiberglass seat in figure 4 (Leppek, 2012).

Figure 4: Seating arrangement of airboat

Drive Unit, Rudders and Shroud - Drive unit framework was encompassed with mild steel tubing. According to the size of the engine, size of the tubing was matched to construct the structure. Subsequently, a propulsion system was fixed to the hull structure by mild steel frame. Then, the engine framework was fixed to the runners located on the floor of the hull by bolts. The fan guard was connected to the engine framework. In this design, there is no reduction gear box and the propeller is directly coupled to the engine. The whole frame work is connected to the propeller shroud and engine structure. Split clamp collars are located on either side of the bearing blocks, and these collars hold onto the propeller shaft and limit forward and backward movement. Sizing of the propeller shaft and support framework, along with the bearing blocks and split clamp collars is reliant on the amount of thrust produced by the propeller (Leppek, 2012).

Propeller guard scale was determined depending on the size of the propeller is used for the airboat. In this construction of the propeller shroud consisted of mild steel and tubing that is used to create a framework for the guard. Major rings of shroud were made by 1" pipes and supporting elements were fabricated with ½" pipes. Spacing of the tubing used for the framework was kept wider with a wire mesh (12 gauge) in figure 5.

Figure 5: Propeller guard

This airboat was fixed with two rudders for easy operation. A sink coated sheet was utilized to develop these rudders with an airfoil shape. Subsequently, a push/pull cable or a connecting linkage was attached to a

directional control stick located next to the driver's seat which allows the operator to control the movement of the rudders in figure 6. By controlling the movement of the rudders, the operator is able to steer the airboat by directing the airflow from the propeller. An acceleration pedal is located on the floor in front of the driver permits them to control the speed of the airboat. This throttle pedal was connected to the engines fuel system, and it regulates the amount of fuel entering to the combustion chamber (Sun and Faltinsen, 2007).

Figure 6: Rudders

Principle of Operation - According to the Newton's third law of motion, the propeller exerts a force on the air and pushing it backwards behind the boat. Simultaneously, the air exerts a force on the propeller and move the airboat forward. Further, a motor fan is apparently the propulsion of choice for most planing hull flat bottomed craft, with vigilant hull integration, and it leads to reduce power requirements relative to an open screw propeller. Moreover, rudders are fixed an above the water line which create a favorable propulsion / hull interaction (Savitsky, 2003).

Calculations of Powering - The following expression at the equation (1) can be stated to quantify generated force by the airboat (Sun, H. and Faltinsen, O.M., 2007).

$$F = ma \qquad (1)$$

The following expression at the equation (2) can be stated to enumerate initial velocity and final velocity of the airboat.

$$V = u + at \qquad (2)$$

The following expression at the equation (3) can be stated to estimate drag force by the water.

$$F_{drag} = \frac{1}{2}\rho C_d A V^2 \qquad (3)$$

Where,

F is force
m is weight
a is acceleration
u is initial velocity
V is final velocity
t is time
F_{drag} is dragging force
ρ is density of water
C_d is drag coefficient
A is cross section area of the hull, up to water line

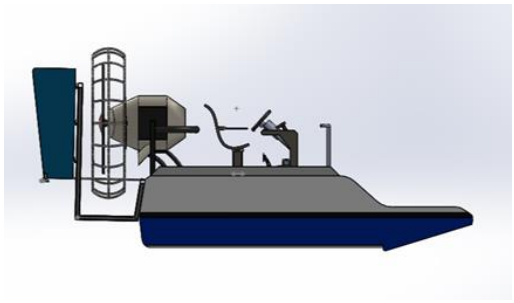

Figure 7: Schematic of airboat

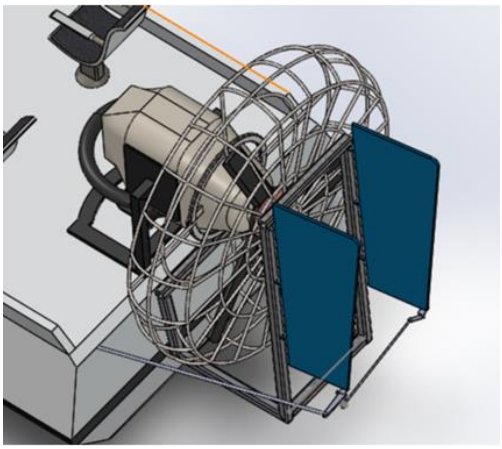

Figure 8: Schematic of airboat drive unit

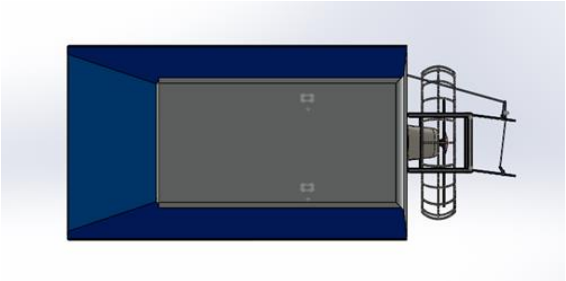

Figure 9: Schematic of airboat steering system

The final velocity of the airboat (V) is determined by equation (4).

V=15 knots = 0.514 × 15 = 7.7 m/s
Where U = 0
ρ = 1000 Kgm^{-3}
C_d = 0.5
A = 0.19 m^2
Net Force (F_n) = Force (F) + Dragging Force (F_d) (4)

The net force of the airboat (F_n) is determined by equation (16).

F_n = (7.7/20).500 + {0.5 x 1000 x 0.19 x (7.7)^2}
F_n = 192.5 + 2816.275
F_n = 3008.775
Power (P) = F_n× V (5)

The power of the airboat (P) is determined by equation (5).

P = 3008.775 × 7.7
P = 23167.5675 W
P = 23.17 kW
Adding 10% Safety factor =(23.17+2.317)kW
= 25.487 kW
Converting to HP = 25.487/ 0.742
= 34.15 HP

Considered the propeller efficiency up to 95% and selected 35 HP engine suitable for air boat.

Results

Speed Trails - The speed trails were conducted in two occasions with different load conditions. In initial trail was carried out with light load conditions for two hours in figure 10. Consequently, speeds of air boat were obtained by handheld GPS and details in table 1.

Figure 10: Conducting a half load trails

Table 1: Light load condition parameters

Load Condition (kg)	Engine rpm	Speed (knots)	Remarks
425	1800	6	Heavy vibration
	2400	8	Bit vibration
	3000	12	Bit vibration
	3600	15	Bit vibration, belt slipped

Figure 11: Conducting a full load trails

Maneuvering Trails - A maneuvering trial was carried out to determine the maneuverability and directional stability of the airboat. Further, the trails were extended up to carry out a direct and zig-zag movements of the airboat in both light and full load conditions in figure 12.

Figure 12: Conducting a maneuvering trails

Discussion

According to classifications of fiberglass resins, it is generally divided into three types, such as polyester, vinylester and epoxy. Each one is having a prominent place in the boat building venture. In this design, the polyester is chosen to fabricate this airboat hull due keep the airboat in light weight condition with more strength.

An air craft engine was fixed with this airboat due high fuel efficiency, light weight, very less maintains and greater power to weight ratios. Further, there was no gear box in this design and an engine was directly coupled with a propeller to minimize a top weight. This propeller was matched with the engine, as per assigned task by SLN. The propeller is made up with carbon composite material and comprised with three blades, including flat tips to regulate the rpm below 3000. In general, the maximum tip speed of a propeller is around 890 feet per second. Though, airboat operators are ensuring that the tip speed should not be reached to maximum value, in all time to avoid sudden occurrence of failures. In addition, it naturally gives the maximum thrust during this maximum tip speed, same time developed trust could be lost, in quick intervals due aerodynamic occurrence of the propeller and then it leads for catastrophe.

In the process of speed trails, a great amount of ambient noise and bit vibrations were observed. Subsequently, all the engine mounting bolts were tightened and brought down the vibration into minimum level. The driving belt was slipped twice at when engine approaches 3600 rpm. Though, it was fixed after tightening the belt by adjustable pulley.

A maneuvering trail was little complex compared to speed trails, and observed that the bow of the hull moved through the water with less resistance prior to the airboat planing out. Then airboat was carried out sharper turns and zig zag movements and checked behavior of the airboat. Finally, it was suddenly reduced the speed and quickly the wake created by the hull and splashed against the transom and fair amount of water came over the gunnel. Both occasions of trails, airboat speed was restricted to 15 knots, to avoid reaching maximum tip speed of the propeller.

Since this design is compatible for accommodating approximately 12 passengers, research and developments are underway to develop an airboat with 2 passengers. This airboat is novel product for Sri Lanka and versatile to operate in rescue work, during floods. It can be easily transfer for flooded area by a vehicle and handled it by four men, without making any complexities. Further, this boat can be easily maneuvered, in both steady and moving waters, without risk. Besides, an endurance is quit high and can be operated at continuance six hours in a single stretch. Finally, this airboat is suited to operate in uncertain small depths, even the flood is receding.

Conclusion

It is recommending that to fix suitable silencers to minimize ambient noise during the operation. Further, recommended to fix a splash guard with a height of 15 cm on top of the transom to minimize splashing during sudden stops of airboat. Furthermore, recommended to fix a fire extinguisher one of the legs of the driver seating structure, to use in case of emergency. Finally, operability of this air boat was very good in both steady and rough waters and provides sustainable solution for rescuing victims during flood situations.

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Paper ID 370

Development of a Robust Dynamic Damage Control Simulator

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Abstract: The art of 'Damage Control' has been part of a seafarer's professional expertise for time immemorial. The utility of effective damage control as well as the disastrous consequences of lack of it, in modern Naval combat, was once again very painfully reminded during the Falklands War in 1982. Consequently, the discipline of 'Damage Control' underwent some of the most radical changes as part of the lessons learnt exercise at the end of this war. The resultant overhaul of the damage control system, onboard Naval ships, envisaged wide-ranging improvement in many facets of naval warfare ranging from basic outlook towards damage control to rudiments of ships design itself. However, the most significant part of this process was to train the basic human response, in the face of a catastrophe, from essentially a crisis management exercise to a systematic application of resources. Needless to say extensive and realistic training forms the cornerstone of this evolution of transforming damage control from the chaotic response into a symphony of 'right actions' in this endeavour, while the technology bridged the gap between available and desirable, simulators helped in recreating realistic scenarios under a controlled environment to extract maximum benefits of training (Valera and Soares, 2007).

Keywords: Damage Control, Battle Simulation, Crew Competency

Introduction

The Damage Control Simulator (DCS) is fundamentally a training method that simulates a realistic and stressful, nevertheless a controlled environment for crew training in ship damage control and repair in various damage scenarios (Bulitko and Wilkins, no date b). Further, DCS can be utilized for crew training in both war and peace times equally. Subsequently, to encompass the damage and save the vessel, the crew needs to be able to respond to the threat with efficiency, expertise and confidence gained from training in similar situations. The realistic damage scenarios and crisis generated in the DCS contributes invaluably in driving away fear among the trainees and in improving team building traits, thereby preparing them for unforeseen hardships and emergencies at sea.

Figure 1: Damage control simulator, Malaysian Navy
Source: (*Damage Control Training unit — Protankgrüp*)

Static Damage Control Simulator

The erstwhile static damage control simulator was a fixed structure simulating a two-deck arrangement of a ship with usual ship fittings to simulate ship-like experience while performing damage control exercises. Even though this been a useful tool in

training onboard crew members, it lacked fundamentally in its ability to simulate rolling and pitching motion of a ship during the exercises. The importance of simulating ships motion during any shipborne simulation exercise cannot be overemphasized (Bulitko and Wilkins, no date a). However, in the case of a damage control exercise, it assumes even more criticality because unlike other facets of training which can be replicated at sea, a realistic damage control exercise can only be conducted ashore and therefore simulation of ships motion gains paramount importance to infuse reality in the conditions. Naval and Maritime Academy has not lagged in assimilating this evolving discipline and had started imparting systematic training in damage control to naval personnel quite early. The pioneering effort in the direction of damage control simulation was made by Cdr VC Munundradassa (Retd), who designed and built a static damage control simulator in 1992 and installed it at the Engineering School. Subsequently, this static damage control simulator was shifted to its present location at Nuclear, Biological, Chemical and Defence (NBCD) School in the year 2000 when a separate school was established exclusively for firefighting and damage control training.

Methodology

Figure 2: Static Damage Control Simulator

In order enhance the realism in the damage control environment simulated at NBCD School and thus the training value of damage control training, the erstwhile static damage control simulator has now been transformed into a dynamic simulator with innovative application of available resources and ingenious efforts by the staff of Naval and Maritime Academy. These modifications transforming static simulator into dynamic simulator were completed on 08th August 2006 and subsequently, the simulator was christened as “Mahasen”. With these modifications, the static simulator has now been mounted on a pivot arrangement and incorporated with a tilting mechanism to induce rolling motion to the entire structure. The desired 15 degrees of a roll of the structure is achieved with the help of a 5.5 kW electric motor and a drive mechanism of a worm wheel and shaft assembly. Apart from this major modification, the simulator has also been modified to create more realistic conditions in terms of the acoustic and visual environment inside the simulator. After the modification, the two compartments of the simulator can be flooded with water at a rate of 25 tons per hour providing the capability to completely submerge the entire simulator within approximately 12 minutes. With this infrastructure, various battle damages like leaks, high-pressure pipe bursts, bulkhead damaged can be simulated. Apart from the damage simulation under 15 degree rolling conditions, following environmental conditions can also be concurrently simulated to provide realistic situations during exercises:

i. Total darkness to simulate a power failure.
ii. Air Conditioning to simulate actual ship like environmental conditions.
iii. Smoke generation to simulate a fire incident.
iv. Explosion and other sounds to simulate battle damages.

A. Design Procedure

In this design process, 5.5 kW, 1500 rpm three-phase motor is used as a power source. Then, the motor is connected to the gearbox by 'V' belt. The gearbox can transmit 5.5 kW power, by using only one speed, of 625 rpm. A sliding mesh is encompassed with this design gearbox and input gearwheel is fixed to the shaft, while pinion gearwheels are boxed up with a gear block. The gearbox consists of 02 gear wheels, 02 shafts and bearings.

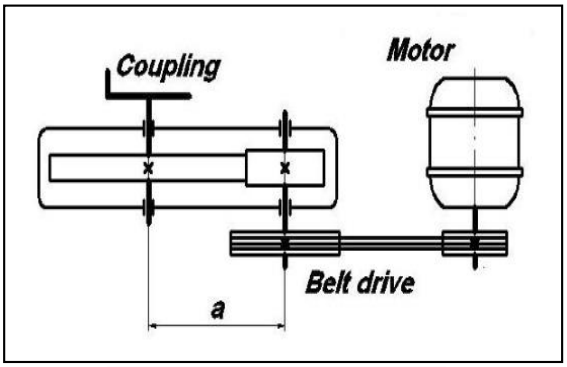

Figure 4: Sketch of Gear Drive

As per the dimensions of Damage control simulator, we neglected geometry of internal compartments in calculating Moment of Inertia of the entire structure.

Design of motor

Moment of Inertia, I

$I = [hb^3/12 - hibi^3/12] \times m$
$I = [6.12 \times (2.04)^3/12 - (2.04 - 8x10^{-3}) (6.12 - 8x10^{-3})/12] \times 8000$
$I = 450.4\ kgm^4$

1 radian = 57.29°
$\omega = 0.1$ rad/ sec
$\alpha = 0.025$ rad/ sec^2
$\tau = I\alpha$
$\tau = 450.4 \times 0.02$
$\tau = 11.26$ Nm

Required power to accelerate the simulator, P

$P = 2\pi nT/60$
$P = 2 \times 3.14 \times 625 \times 11.26/ 60$
$P = 736.96$ Nm

Belt drive efficiency = 85%
Gearbox efficiency = 80%

Actual power requirement, P_1
$P_1 = 736.96/ 0.85 \times 0.8$
$P_1 = 1.1$ kW

Considering the resources available, motor with following specifications has been selected.

Motor power output: 5.5 kW
Motor RPM: 1500
Phase: 3φ

Table 1. Specifications of system

System Specification	Value
Moment of Inertia, I	450.4 kgm^4
Torque, T	11.26 Nm
Required power, P	11.26 Nm
Actual power required, P_1	1.083 kW
Belt drive efficiency	85%
Gearbox efficiency	80%
Selected motor	5.5 kW, 3φ, 1500 rpm

Design of Belt drive and gearbox

Single belt drive is selected to transmit the power to gear box.
Belt coefficient: 2.4
Input drive speed = N_B/ N_A =1500/2.4 = 625 rpm
Required speed for simulator = 125 rpm

Two gear wheels selected for reduction of speed
Gear ratio, G = Input drive speed/ Output drive speed
G = 625/125
G = 5.0

No of teeth in pinion = 20
Module, m = 3 mm
No of teeth in gear = 20 x 5 = 100
Module, m = Pitch circle diameter, D/ No of teeth, Zp
Dp = 3 x 20 = 60 mm
Gear ratio, G = Dp/ Dg
Dg = 5 x 60 = 300 mm

Table 2. Description of belt drive and gear box

Description of Belt drive and Gearbox	Value
Speed ratio	2.4
Input drive speed	625 rpm
Required speed for simulator	125 rpm
Gear ratio, G	5.0
No of teeth in pinion	20
No of teeth in gear	100
Diameter of pinion	60 mm
Diameter of gear	300 mm

Shaft Design

Considering maximum bending moment and torque,
Input shaft diameter, D_1 = 25 mm
Output shaft diameter, D_2 = 30 mm
Material: Mild steel

Selection of Bearings

Bearings subjected to radial loads,
$P = XF_r$
X = 1 for deep groove ball bearing

Radial load of drive end, F_{r1} = Total torque/ Input shaft radius
$F_{r1} = 64.968/12.5 \times 10^{-3} = 5.2 \times 10^3$ N
$P_{Drive} = 5.2 \times 10^3$ N

Radial load of driven end, F_{r2} = Total torque/ output shaft radius
$F_{r2} = 64.968/15 \times 10^{-3} = 4.33 \times 10^3$ N
$P_{Driven} = 4.33 \times 10^3$ N

Life of bearing, $L_{10} = 60\, nL_{10h}/ 10^6$
Working hours per day = 2 hours
Life of bearing = 5 years

Drive shaft bearing
$L_{10} = 60 \times 625 \times 2 \times 5 \times 365/ 10^6 = 136.875$
Driven shaft bearing
$L_{10} = 60 \times 125 \times 2 \times 5 \times 365/ 10^6 = 27.375$
Drive shaft bearing
Dynamic load carrying capacity, $C = P\,(L_{10})^{1/3}$
$C = 5.2 \times 10^3\, (136.875)^{1/3} = 5.2 \times 10^3 \times 5.15 = 26800$ N
Drive shaft bearing
$C = 4.33 \times 10^3\, (27.375)^{1/3} = 4.33 \times 10^3 \times 3.012 = 13042$ N

Table 3. Bearing selection details

Description	For Driving Shaft	For Driven Shaft
Diameter, d	25 mm	30 mm
Dynamic load, P	5.2×10^3 N	4.33×10^3 N
Life of bearing, L_{10}	136.875 rev	27.375 rev
Dynamic load carrying capacity, C	26800 N	13042 N
Catalogue C value	35800 N	19500 N
Designated Deep groove ball bearing	6305	6206
Outer diameter	80 mm	62 mm
Axial width	21 mm	16 mm

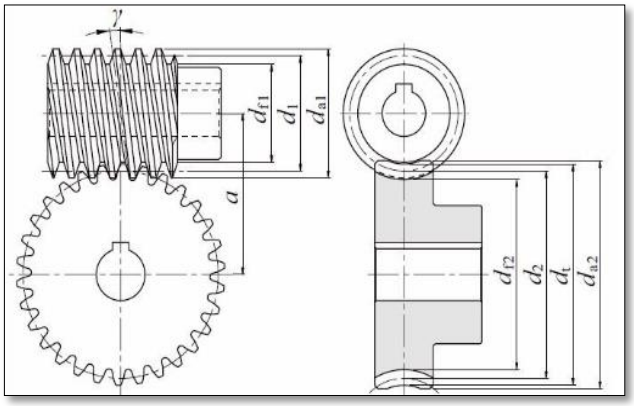

Figure 5: Cylindrical Worm Gear Pair

B. Utility for Training

'Mahasen' can be utilized for training sixteen trainees under the supervision of three qualified instructors at any given time. The realistic damage conditions created by the simulator are of enormous training value as they inculcate team spirit and remove fear from the mind of the trainees, conditioning their responses into orchestrated teamwork

in the face of rapidly deteriorating conditions. The practised response of all personnel in the face of battle damage recreated under the safely of a controlled environment will go a long way in preparing personnel for the actual eventualities at sea. 'Mahasen' is also being utilized to train personnel of the fleet apart from the trainees of the academy and is contributing immensely to the overall preparedness of our Navy.

Conclusion

This DCS is purely utilized to train Sri Lanka Navy personnel, who are assigned on board ships in damage control and repair in different damage scenarios. Further, this training was immensely helped to remove psychological fear, developed leadership skills, enhanced communication skills, team building support and experienced in handling war casualties.

It is recommended to incorporate pitching movement by mechanical means along with rolling motions to enhance the more realistic scenario for crew onboard vessels.

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A Comparison of Nonlinear Material Models Used in Pavement Response Modelling

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Abstract: The numerical modelling of pavement responses is very much influenced by structural properties of pavement. The structural properties are modelled by material models. Clear understandings of pavement responses with respect to the material models are necessary to evaluate the accuracy of prediction. This paper is aimed at investigating the application of an inverse modelling technique to find the material parameters of three different models using Repeated Load Triaxial test data. The method of estimating material parameter values is based on least squares technique. Computations were performed using ABAQUS in MATLAB platform. The results of the computations are compared to each other. Numerical simulations and comparisons show a good agreement between estimated values (modulus, strain, and stress deflection) obtained using three different models.

Keywords: Pavement response; Finite element modelling; USDFLD; UHYPEL.

Introduction

Permanent deformation of pavement decreases its durability and results in serious traffic safety problems. This problem will become more serious with increase in axle loading and repetitions. Therefore, optimal cost and serviceability estimation of new pavement design problem have to be studied carefully. This can be done efficiently using numerical modelling of pavement response. The accuracy associated with modelling pavement response is highly dependent on material model. Inaccuracy in the model can lead to differences between calculated and actual estimation.

Numerical modelling of pavement response may be used during a design process to build the pavements. The pavements response simulation describes the mechanical response of material under axial loads. Several deformation models are available in the literature to study and control permanent deformation in flexible pavements. They use different material models and it depends on stress level. This research evaluates two of the most recent models with the most popular $K-\theta$ model for suitability in the prediction of rutting potential of asphalt mixes.

Material Models

Granular materials make up a discontinuous particulate medium physically and its resilient performance is strongly influenced by the applied wheel load levels and the thicknesses of surface materials overlain. The resilient behaviour of granular materials defined by resilient modulus is influenced by stress level, density, grain size, aggregate type, particle shape, moisture content, and number of load applications. Resilient models of granular materials increase with increasing stress states. There are several mathematical models have been developed using different stress components.

One of the most popular model was developed by Hicks and Monismith [4]. This model, known as the $K-\theta$ model, has been the most widely used for material modeling as a function of stress state

applicable to granular materials. it is given by

$$M_r = K\theta^n. \quad (1)$$

where $\theta = \sigma_1 + \sigma_2 + \sigma_3$, σ_1 σ_2 $\sigma_3$are principal stress, ***K***, ***n*** are material constants.

Then in late eighties researchers found that the $K - \theta$ model was not sufficient to describe the shear behaviour and made some modifications to the model. This model was proposed by Uzan [8]. This was the model used by Bruce Steven [2], [3] in his PhD thesis to develop a nonlinear pavement response and performance model for calibration and verification of two thin surfaced unbound granular pavements. It is given by

$$M_r = k_1 p_a \left(\frac{\theta}{p_a}\right)^{k_2} \left(\frac{\tau_{oct}}{p_a} + 1\right) \quad (2)$$

where

$$\theta = \sigma_1 + \sigma_2 + \sigma_3$$

$$\tau_{oct} = \frac{1}{3}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}$$

$$p_a = 100\ kPa$$

M_r resilient modulus, k_1, k_2, k_3 are constants, σ_1, σ_2 and σ_3 are principal stress. This model will be referred in this paper as the Bruce Steven's model. This model was used to construct granular layers in our previous research works [5], [6], [7].

Werkmeister[9] proposed the nonlinear 'Dresden Model' in her PhD thesis. This nonlinear elastic model is expressed in terms of resilient modulus, E, and Poisson ratio, υ, as follows:

$$E = p_a \left(q + C\left(\frac{\sigma_3}{p_a}\right)^{q_1}\right)\left(\frac{\sigma_1}{p_a}\right)^{q_2} + D(3)$$

$$\upsilon = R\frac{\sigma_1}{\sigma_3} + A\frac{\sigma_1}{p_a} + B \quad (4)$$

where σ_3(kPa)) minor principal stress (absolute value); σ_1 (kPa) major principal stress (absolute value); D (kPa) constant in term of modulus of elasticity; p_a = 1 kPa, q, C, q_1, q_2, R, A and B are model parameters.

Inverse Modelling

Inverse modelling is the estimation of model constants from data. It is a discipline that provides tools for the efficient use of data in the estimation of constants appearing in the models. In our problem, structures of equation are known; measurements of modulus for various different principal stresses are obtained from Repeated Load Tri-axial (RLT) test and given in Table 1. Some of the constants are unknown.

Table 1: RLT test results

Major stress (kPa)	Minor stress (kPa)	Modulus (MPa)
210	120	487
167	66.7	352
142	41.7	289
270	90	446
470	140	585
530	110	549

The goal of this section is to find the optimal values of the constants appearing in Equations 1-4 from the available measurements given in Table 1. Taking natural logarithms of both sides of Equations 1 and 2 gives respectively

$$\ln M_r = n \ln \theta + \ln K \quad (5)$$

$$\ln M_r = \ln(k_1 p_a) + k_2 \ln\left(\frac{\theta}{p_a}\right) + k_3 \ln\left(\frac{\tau_{oct}}{p_a} + 1\right) \quad (6)$$

If the data values are transformed by letting:

$$W = \ln M_r,\ x = \ln\theta,\ X_1 = \ln\left(\frac{\theta}{p_a}\right) \text{ and } X_2 = \ln\left(\frac{\tau_{oct}}{p_a} + 1\right)$$

then Equations 5, 6 for p data values respectively become

$$\begin{bmatrix} \ln M_1 \\ \ln M_2 \\ \vdots \\ \ln M_p \end{bmatrix} = \begin{bmatrix} \ln \theta_1 & 1 \\ \ln \theta_2 & 1 \\ \vdots & \vdots \\ \ln \theta_p & 1 \end{bmatrix} \begin{bmatrix} n \\ \ln K \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} \ln M_1 \\ \ln M_2 \\ \vdots \\ \ln M_p \end{bmatrix} = \begin{bmatrix} 1 & X_{11} & X_{21} \\ 1 & X_{1,2} & X_{22} \\ \vdots & \vdots & \vdots \\ 1 & X_{1p} & X_{2p} \end{bmatrix} \begin{bmatrix} \ln(k_1 p_a) \\ k_2 \\ k_3 \end{bmatrix} \quad (8)$$

The step then is to estimate n, K using linear regression and k_1, k_2, k_3 using multiple linear regression.

But the Equation (3) cannot be linearized easily and therefore we then relied exclusively on MATLAB s routine *lsqnonlin* to find the constants appearing in Equation (3). For p data values Equation (3) can be written as

$$\mathbf{E} = f(\mathbf{P}) \quad (9)$$

where $E = [E_1\ E_2, \cdots E_p]$, $P = [q, C, q_1, q_2, D]$ and $\boldsymbol{f}$ is a function. To estimate $\boldsymbol{P}$ following minimization problem is solved.

$$\text{minimize} \quad \mathbf{Z} = \|f(\mathbf{P}) - \mathbf{E}\|_2^2, \quad (10)$$

where $f(\mathbf{P})$, $\mathbf{E}$ are vectors containing estimated and measured modulus values respectively and $\mathbf{P}$ is the vector of unknown values.

All of the above mentioned models except the Sabine's models uses constant poisson ratio. We therefore investigated the effect of assuming constant poisson ratio on Sabine's model. For this investigation we simulate the pavement response model with Sabine's Equation (3) for the poisson rations 0.2, 0, 3 and 0.4. Results of the comparison are summarized in Figure 1. Figures A, B, C and D respectively illustrates variation of modulus, vertical strain, vertical stress and vertical displacement along the vertical axis under the center of the wheel. These results suggest that the effect of keeping constant poisson ratio on modulus, stress, strain and displacement are minimal.

Listed in Tables 2, 3 and 4 are the estimates of constant values for the $\boldsymbol{K-\theta}$, Bruce and Sabine's models for the data value given in Table 1 and poisson ratio of 0.35.

Table 2: $K-\theta$ model

k	n
343860	0.55

Table 3: Uzan's model

k_1	k_2	k_3
1790	0.7458	-0.3455

Table 4: Sabine's Model

Q	C	q_1	q_2	D
14004	6540	0.35	0.33	$65x10^6$

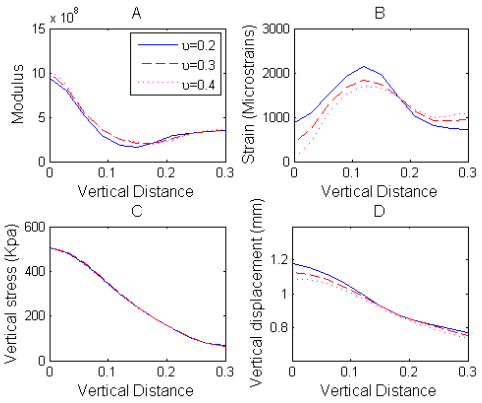


Figure 1: Effect of Poisson Ratio

Finite Element Model

The general purpose finite element program ABAQUS is used in this investigation to simulate the deformation process as shown in Figure 2. By making use of symmetry in the geometry we only considered the quarter of the model. FEM model contain only two layers. The top layer is 300 mm height and modulus of elasticity is modeled by the equation (3) and the poisson ratio of 0.35. The bottom

layer has a height of 1200 mm with modulus of elasticity of 24 MPa and a posson ratio of 0.4. The length and width of FEM section is 750 mm.

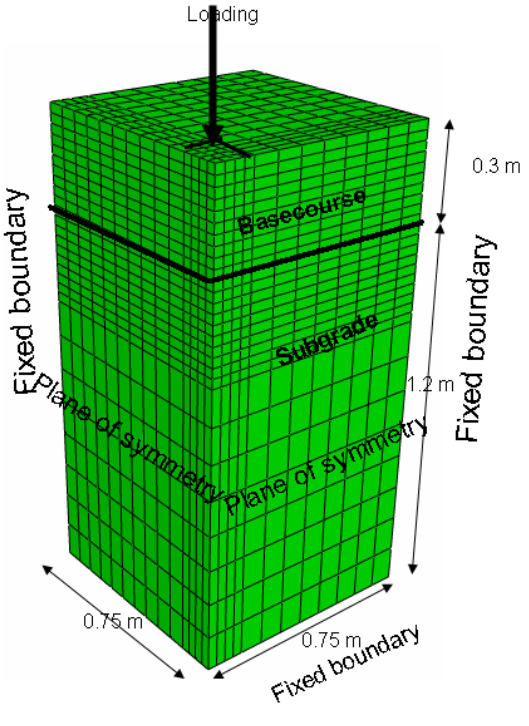


Figure 2: FEM Model

Subroutine

The material model described in Equation (1), (2) and (3) are implemented in ABAQUS using the user-written subroutine USDFLD and UHYPEL. Figure 3 illustrates the structure of the user defined subroutine. The most simple usage of this routine defines modulus in terms of strain but in our case modulus is a function of stresses. Stress are brought into the UHYPEL subroutine via the use of user predefined fields.

The subroutine USDFLD allows the user to define field variables at every material point of an element and provides access to a number of variables such as stress, strains. A utility subroutine GETVRM is used to access these variables at every material point in the calculation domain. The subroutine USDFLD is used to calculate the absolute values of principal stresses and passed into the subroutine UHYPEL.

Results and Discussion

In this section, we present numerical calculations to evaluate the differences between model predictions. To do so we consider the pavement comprised a 300 *mm* thick layer of granular material placed directly on top of a 1200 *mm* thick sub base. The length and width of the loaded area in the quarter 3D model is 124 *mm* and the contact stress is 0.510 Nmm^{-2}. The results of the simulation using three different material models are given in Figures 4, 5, 6 and 7.

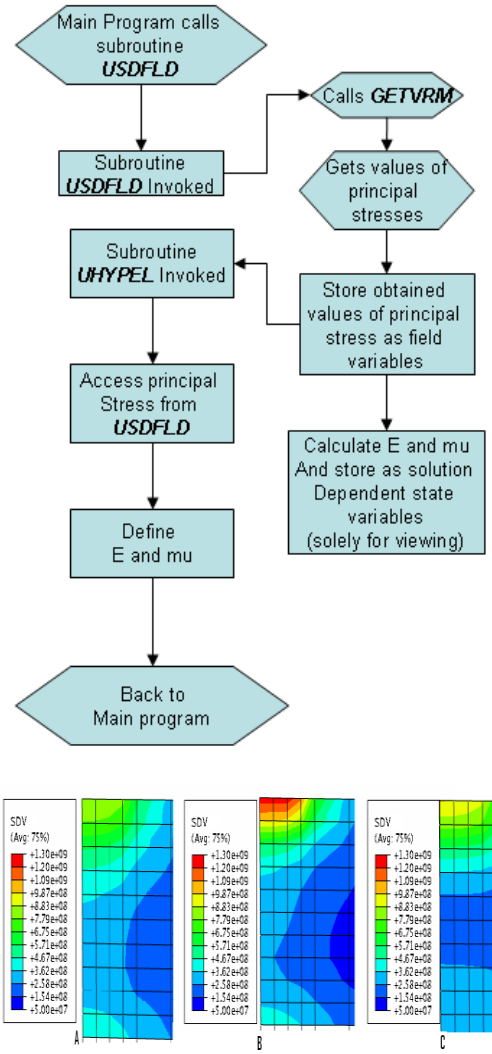


Figure 3: USDFLD.

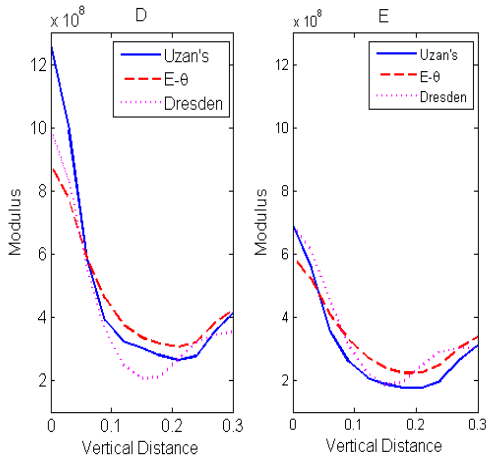
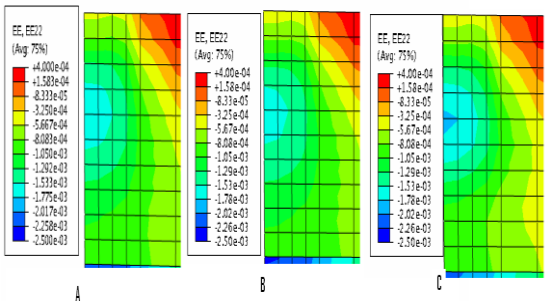


Figure 4: Modulus: (A)E□_ model, (B) Uzan's model, (C)Sabine's model, (D) Modulus at the center, (E) Modulus at the edge.



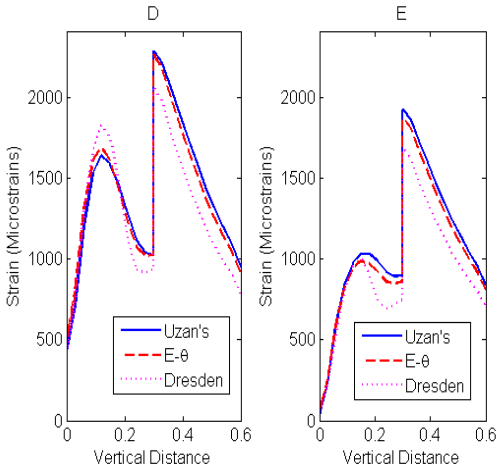
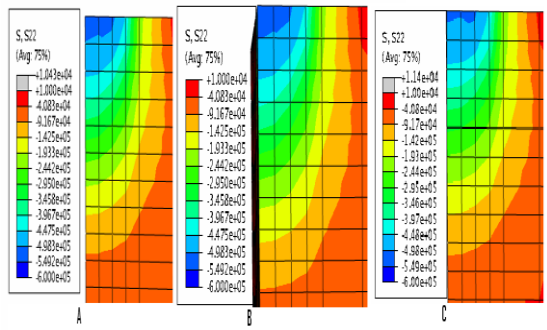


Figure 5: Vertical strain: (A)E □ _ model, (B) Uzan's model, (C)Sabine's model.



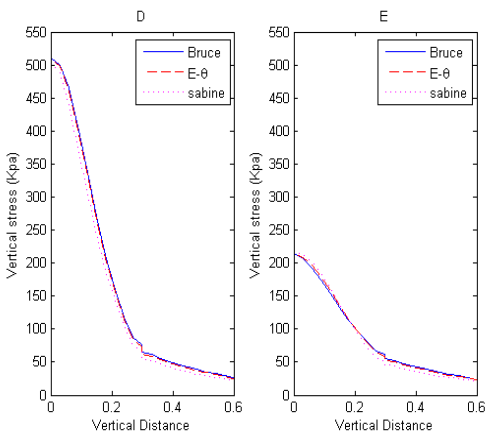


Figure 6: Vertical stress: (A)$E-\theta$ model, (B) Bruce's model, (C)Sabine's model, D) Modulus at the center, (E) Modulus at the edge.

Figures 4 A, B and C show the contour plot of modulus under load contact area for three models respectively. The modulus variations along the vertical axis under the centre of load contact area and at the edge of the load contact area are given in Figures 4D and 4E respectively. It can be seen that results are very close except near the top surface and near the middle of the base course.

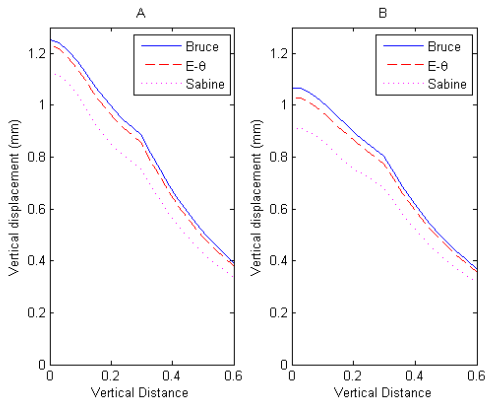


Figure 7: Vertical displacement: (A) at the center, (B) at the edge.

Figures 5 A, B and C show the contour plot of vertical strain under load contact area for three models respectively. The vertical strain variations along the vertical axis under the centre of load contact area and at the edge of the load contact area are given in Figures 5D and 5E respectively. It can be seen that results are very close except the magnitude of the peaks. Sabine's model slightly over estimated the strain values

near the centre of the base course material and under estimated near the bottom of the base course. The strain values inside the sub base also influenced by the strain values near the bottom of the base course layer.

Figures 6 and 7 respectively shows the vertical stress and displacement under load. Stress values are very close. The vertical distance and magnitude of stress values are well matched.

Summary and Discussion

The intention of this paper is to demonstrate an inverse model capable of concurrently estimating the material constants of (1) E –Θ, (2) Uzan's and (3) Sabine's material models using the RLT experimental data. The approach is based on a least squares estimation using simulated strain value and coupled with Finite element technique.

A finite element model was developed using ABAQUS to predict the deformation behaviour of flexible pavement structure subjected to a static and dynamic loads. The results obtained using three different material models mentioned above were compared. A comparison between the results suggest that results obtained using both models are nearly same.

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Paper ID 383

Energy Absorption Capacity and Impact Energy of Rubberized Concrete

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Abstract: Disposal of used tires is a critical environmental issue in Sri Lanka. Rubberized concrete is one of the solutions introduced by the researchers to minimize the quantity of waste rubber. These studies discovered that rubberized concrete is an ideal alternative for lightweight concrete. However, they further revealed that the compressive strength of concrete degrades with the addition of rubber. Further, the durability of rubberized concrete is still questionable. However, due to the energy absorption capacity of rubber, rubberized concrete have the potential of possessing higher energy absorption capacity.This property of rubberized concrete along with the lightweight will make rubberized concrete an ideal alternative for road barriers. Hence, this study focuses on exploring the static and dynamic energy absorption characteristics of rubberized concrete. Mix designs for grade 25 concrete was done while partially replacing fine aggregate by rubber crumbs at proportions of 5%, 10% and 15%. . The energy absorption due to static loads were measured from plate test and impact energy, energy absorption and shock absorption due to impact loads were calculated from artificial athlete test. The experimental results show that the compressive strength and density of rubberized concrete reduces as the percentage of rubber increase. The low density quality can be used to make lightweight concrete. But significant improvement in shock absorption, Static energy absorption capacity, impact energy and energy absorption capacity can be seen. Due to high energy absorption against dynamic loads, the rebound force get decreased. Therefore rubberized concrete can be used in structures which are prone to impacts to create less impact on the object which collides with the structure. This characteristics make rubber concrete ideal for rigid roadside barriers, foundation pad for machinery, railway buffers and bunkers where the energy and shock absorption more important than the strength.

Keywords: concrete, rubber, fine aggregates, absorption capacity

Introduction

Current studies have shown that approximately 10 billion tires are discarded in one year globally. Further, about 1 billion crumb rubber waste is generated from the tire manufacturing factories annually (Polgar *et al.*, 2018). Contribution of Sri Lanka to that quantity of waste is about 3.2 million (Resources, 2005) per year from imported and manufactured tire waste. Only a small portion of this rubber waste is used for such as rail foundations and highway embankments, energetic purposes in cement kilns, electricity production process, additive for pc mortar or concrete and as a lightweight filler.A major portion is dumped as landfills which inturn creates several environmental issues.

Among several solutions suggested by researches to re-use this rubber waste, rubberized concrete has also been identified as a viable solution(Sukontasukkul and Wiwatpattanapong, 2009). Several studies have revealed that rubberized concrete is

lightweight. Compared to the cost of conventional lightweight concrete made with the help of lightweight aggregate, rubberized concrete possess higher economical benefits. However, it has also been discovered that the addition of rubber crumbs cause reduction of compressive strength compared to the conventional concrete of the same grade(Gerges, Issa and Fawaz, 2018). Further, the durability concerns of rubberized concrete is also still at a questionable state. Therefore, use of rubberized concrete has still been limited to applications such as in highway constructions as a shock absorber, in sound barrires as a sound absorber and in buildings as an earthquake shock-wave absorber.

Rubberized concrete has the potential of having higher energy absorption capacity owing to the high energy absorption capacity of rubber. This feature may be helpful in case of structures where energy absorption and impact energy is important such as road barriers, shooting houses and firing ranges. Therefore, this study focuses on exploring static and dynamic energy absorption characteristics of rubberized concrete.

Methodology

The study was purely based on the experimental approach. Fine aggregate was replaced by rubber crumbs at proportions of 5%, 10% and 15% to identify the variation of properties as the rubber percentage increases. The average particle size of rubber crumbs that was taken to this study is within the range of 0.2-0.5mm. The rubber particles were soaked in 10% diluted sodium hydroxide (NaOH). This process is expected to avoid rubber particles from floating in the water. Further, this process has also been proven to improve the bond between cement and rubber as well(Khitab *et al.*, 2017)(Specification, no date). After soaked in NaOH, rubber crumbs were drained and soaked and rinsed three times with fresh water to again neutralize the pH value.

Before preparing the samples, Sieve Analysis was done as per ASTM C 136-05 (ASTM 2016) for all the three proportions of rubber crumbs in fine aggregate to see whether the partical size distribution is acceptable. Upon conforming the accuracy of partical size distribution, mix design were prepared for grade 25 with water cement ratio of 0.5. Once the concrete mixes were prepared slump readings were obtained for different mixes. Samples required for three tests namely; compression test, Static energy absorption test and shock absorption test were prepared.

1) Compression Test: Twelve samples from four mixes (i.e 0%, 5%, 10% and 15% of rubber) were prepred for the compression test. The test was done as per the standard of American Society for Testing and Materials (ASTM). Cubes were tested after 28 days of curing.

2) Static Energy Absorption Test: Test was done as per EFNARC plate test method(Pham *et al.*, 2019). A test specimen of 600 x 600 x 100mm supported on its four ends and a center point load applied through 100 x 100mm contact surface. The rough side of the specimen out in the bottom during the test because the load is applied opposite to the laying direction. The deformation rate of the midpoint fixed as 1.5mm per minute.

Two cuboids were prepared from the mixes with 0 and 10% rubber crumbs to obtain static energy absorption capacity from the energy absorption test. These cuboids were tested after 7 days of curing. The arranged specimen stored under the water for at least three days before the testing and kept moist during testing.The load-deformation curve recorded and the test continued until a deflection of 25mm is achieved at the center point of the cuboid.

3) Shock Absorption Test: This test was done as per the European Standard, EN 14808:2005 (Demker, 2009). A free weight was allowed to fall on to a spring that placed on the test piece and the maximum force applied was recorded. Then the free weight was allowed to fall on to a hard surface and maximum forced measured. The difference between the maximum forces in test piece and hard surface is reported as the reduction of force.

The falling weight have 20kg (±0.1) mass with hardened striking surface. The weight is allowed to fall vertically and smoothly and minimum friction. The gap between test piece and the free weight was setup as 250(±2.5) mm. The peak impact force applied to the surface is recorded. After peak force was recorded, the procedure was repeated at least 10 times for both conventional and 10% replacing rubber samples and get mean value. The size of the test specimen was 100 × 200 × 80 mm .Then the force reduction (shock absorption) was calculated using equation 2. This procedure was done further until the 1st crack occur and the number of blows applied to test piece was noted. Then the Impact energy was calculated using equation 1.

$$IE = N\ m\ g\ h \quad (1)$$

Where:
IE = Impact energy (N m)

N = Number of blows to 1st visible crack
m = Mass of the drop weight (kg)
g = Gravitational acceleration=9.81 m/sec^2
h = Height of drop weight (m)

$$R = (1-P/Q) \times 100 \quad (2)$$

R = Force Reduction [shock absorption (as a percentage)]
P = Maximum Peak Force for test piece (in rubberized concrete sample)
Q= Maximum Peak Force for concrete (in conventional concrete sample)

Results and Discussion

A. Slump

The results of the slump test are shown in Figure 1. It can be seen from the figure that the slump value and hence the workability of concrete decreases with the increase of rubber percentage. The drop of slump value of the concrete with 15% rubber is about 33.3% compared to the control samples which has no rubber.

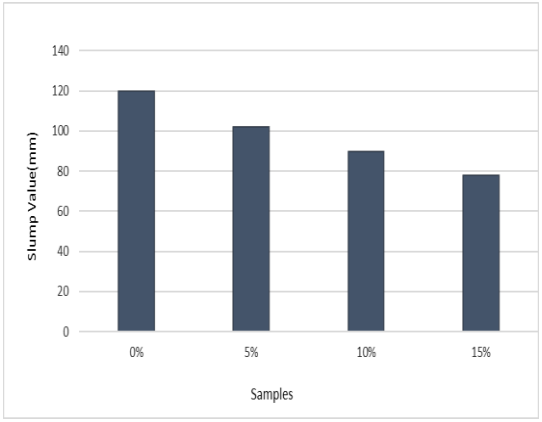

Figure 1. Change of Slump

B. Density

The density of the rubberized concrete was found significantly lesser than conventional concrete. The results are summarized in figure 4. It can be seen that when 15% of fine aggregate is replaced with rubber crumbs, reduction of density is approximately 10% of the conventional concrete of the same grade. This quality of rubberized concrete is beneficial for some applications of concrete.

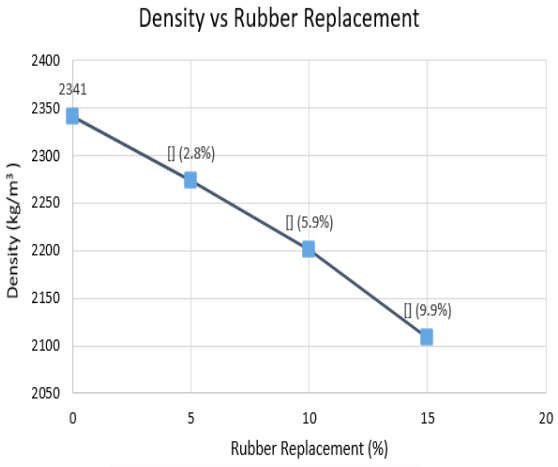

Figure 2. Change of Density

C. Compressive Strength

Variation of compressive strength with the variation of rubber content in concrete is shown in Figure 3. It is obvious from the figure that there is a significant decrease in compressive strength as the percentage of rubber increases in the concrete. When the percentage of rubber crumbs is 15% of the fine aggregate, the reduction of compressive strength is approximately 66% compared to the compressive strength of the conventional concrete of the same grade. Similar observations are reported under the "study on waste tyre rubber as concrete aggregate" This is the biggest disadvantage of rubberized concrete which limits the applications of it.

When observing the failure patterns, inclined shear cracks were observed in conventional concrete samples, while in the rubberized concrete samples, horizontal cracks were observed. This is due to the low compressive strength of rubberized concrete.

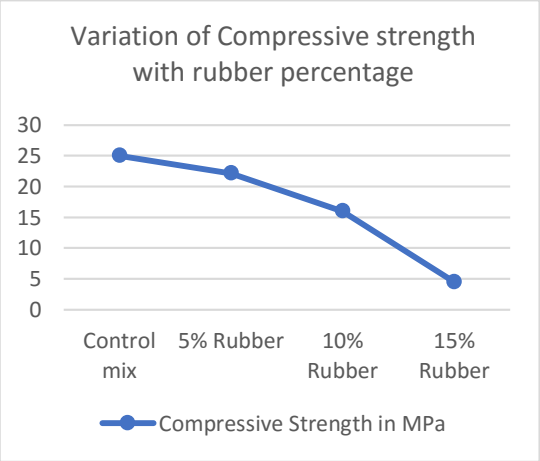

Figure 3. Variation of compressive strength

D. Static Energy Absorption

Static energy absorption capacity (toughness) is the area under the stress strain curve of a compressive test or load deflection curve of a flexural test and the units of toughness is taken as Joule per cubic meter. Here the flexural test was done and hence the area of the load deflection curve was taken in calculating the toughness. The results of the test are given in Table 1. It was noticed that the maximum load of rubberized concrete is about 50% of the maximum load of conventional concrete. However, the displacement at failure of rubberized concrete is about double the value of the same for conventional concrete. Hence, the energy calculated by taking the area under the load deflection curve is approximately 12% higher for rubberized concrete. Therefore, it is evident that despite the reduction in strength, the toughness which is a measure of energy absorption capacity under static loading is higher for rubberized concrete compared to conventional concrete.

Table 1. Static Energy Absorption Results

Rubber Replacement (%)	Maximum load (KN)	Displacement (mm)	Energy (J)
0%	40.15	7	72
10%	19.84	15	81.5

E. Impact energy and energy absorption due to impact loads

The Impact energy was measured in eight samples from four mixes (i.e 0%, 5%, 10% and 15%). The results are given in Figure 4 and it can be seen that as the percentage of rubber crumbs increases to 5% and 10%, the impact energy also increases. Significant increment of 47.6% is observed when the percentage of rubber is 10%. However, at 15% of rubber content, a slight reduction of impact energy compared to the 10% rubber content can be seen. This could be due to the considerable reduction of compressive strength (66% compared to conventional concrete) observed in this sample of rubberized concrete. However, the value of impact energy in this sample is also still higher than the impact energy of conventional concrete. Therefore, it is evident from the results that addition of

rubber crumbs can provide significant improvement to impact energy of concrete.

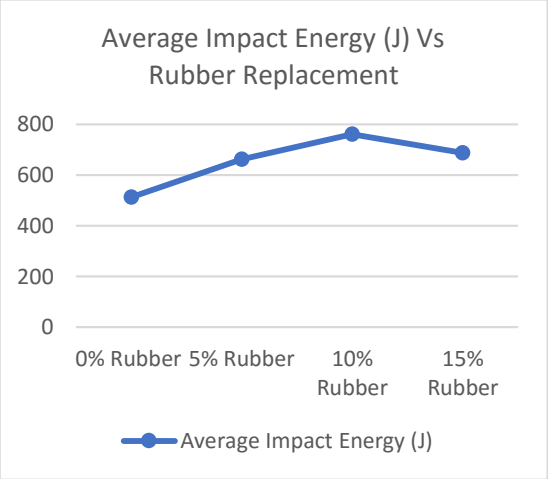

Figure 4. Variation of Energy with Rubber Replacement

F. Shock Abosrption

Shock absorption is calculated by considering percentage reduction in the maximum peak force compared to the conventional concrete sample. The results are shown in Table 2 from the results that shock absorption also increases as the rubber content increases. Maximum increment of shock absorbent is noticed as 8.75% which occurs for the samples with 15% rubber content.

Table 2. Shock absorption results

Rubber Preparations (%)	Maximum peak force in conventional concrete (Q(N))	Maximum peak force in test piece (P(N))	Shock absorption (%)
5	9424.919	8908.1715	5.45
10	9424.919	8734.088	7.3
15	9424.919	8604.653	8.75

Conclusions

Being in an agreement with the previous studies reported in the literature, density and also the compressive strength of concrete were found to decrease as the rubber content of concrete increases. Although, the density reduction is beneficial for some applications, the reduction in compressive strength is a major weakness in rubberized concrete. It was noticed that when 15% of fine aggregate was replaced by rubber crumbs, the reduction of compressive strength is approximately 66%. Further, the reduction in density is also not as significant as the lightweight concrete produced using the lightweight aggregate. The lowest density observed in this study was 2109 kg/m^3 where as the lightweight concrete can have densities as low as 1400 kg/m^3. However, the cost of rubberized concrete may considerably be lesser than the lightweight concrete. Further, the slump also found to decrease with the addition of rubber. However, this issue may be solved with the use of admixtures and additives.

Despite the above mentioned disadvantages, the results of this study revealed that rubberized concrete has better impact and energy absorption properties compared to the conventional concrete. The maximum increment of toughness reported in this study was 12%. Meanwhile, a significant increment of 47.6 was observed in impact energy. Also, the increment in shock absorption is observed as 8.75%. Therefore, it is clear that rubberized concrete is beneficial for structures where low strength but high impact and energy absorption properties are important such as road barriers. However, concrete mixes have to be carefully designed to achieve the optimum combination of properties to suit the applications. It is also important to pay attention to the cost factor as well. As rubber crumbs is a waste product, there is a high possibility of producing low cost structures using rubberized concrete. In

addition, the environmental benefits achieved through the use of waste rubber must also be considered as an added advantage to the use of rubberized concrete.

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Evaluating Driver Speeding at Traffic Signal Lights During the Amber Time: With and Without Countdown Timers

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Abstract: At the onset of amber color indication, drivers must decide whether to stop or cross a signalized intersection. In literature, there is enough evidence indicating that a significantly high number of crashes that occur at signalized intersections are of vehicles entering the intersection during amber and red-light indications. However, such findings cannot be stated for Sri Lanka with the lack of details in the crash records. With that gap of knowledge in the local literature, this study investigated how countdown timers (CDTs) impact on the speeding behavior of drivers. With that aim, the objective of this study was to examine driver speeding according to the distance to stop line (DSL) with the presence an absence of countdown timers (CDT). Two intersections with CDTs and one without a CDT in Colombo, Sri Lanka were considered for data collection. The number of vehicles that are speeding at the onset amber, were considered during a peak hour. These values were obtained for the intersections with and without CDTs as well as for Peak and Off-peak conditions. It was found that the dilemma zone was within 15m to 30m from stop line for intersections with CDTs. Results showed that the presence of a CDT showed no significant impact on the number of vehicles that went speeding at the onset of amber, and it was around 22 veh/ 100 cycles. On the other hand, there was a 35% reduction in the number of speeding vehicles per signal cycle during the off-peak hour with the absence of a CDT.

Keywords: Amber time, Dilemma zone, Intersection safety, Countdown timers, Speeding

Introduction

Amber interval plays an important role in signalized intersections while there are two amber intervals on a signal board (See Figure 1). They are green indication changing to amber and red indication changing to amber. There is a risk associated with the amber time at signalized intersections, because the drivers have to make a decision whether to stop or cross the intersection at the onset of the amber.

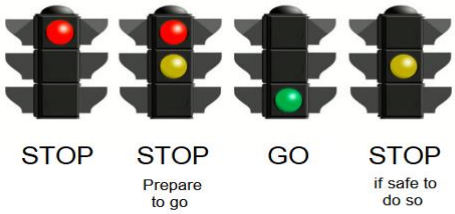

Figure 1. Traffic lights four states
Source:(Petnga and Austin 2016)

The dilemma zone is a zone where drivers may make a decision whether they cross or stop during the amber indication. The dilemma zone associated with problems such as vehicle crashes and red light running results of incorrect driver decisions at amber intervals. Sometimes, drivers decide to stop when they have the ability to drive through an intersection may create unnecessary vehicle traffic and when a driver decides to drive through an intersection when the vehicle should be stopped may create vehicle crashes.

Several studies have been conducted all over the world considering driver behavior at signalized intersections during the amber period considering the factors mentioned. Driver decisions at the onset of amber may vary according to factors such as driver age, driver's gender, vehicle conditions, distance to stop line, speed of the vehicle, road conditions, the presence of countdown timers and etc.

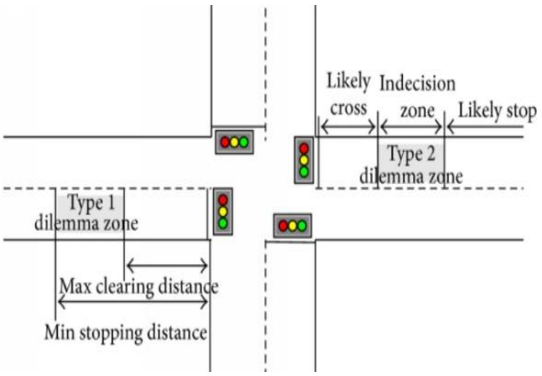

Figure 2. Dilemma zone
Source:(El-shawarby, Amer, and Rakha 2000)

Problem Statement

During the amber light, drivers require a take decision to either stop or go through the intersection. This can lead to unsafe driving conditions deue to confused drivers. When drivers stop their vehicles when the best choice was to cross, it may create and right-angle accidents with side street traffic and red-light running may arise when driver go when it was better to stop (El-shawarby, Amer, and Rakha 2000). According to statistics, out of the all crahses at signalized intersections, crashes in amber light have exceeded half of the entire accidents (Yang et al. 2014). However, Sri Lankan crash reporting system does not capture the data where it says whether the vehicle subjected to crash was running a red-light or had it entered the intersection during the amber time. Hence, a research gap is also identified.

Objectives

To assess driver speeding according with the presence of countdown timers and distance to stop line.

To assess the differences of driver the above parameter in the peak hours and off-peak hours

Methodology

Intersection A, B and C were the three intersections selected for this study as shown in Figure 3. Locations of the intersections were, Intersection A: Golumadama, Intersection B: Maliban junction, and Intersection C: Bellanthota (Attidiya/ Nugegoda). Out of these intersections, A and B were with CDTs and C was without a CDT.

Figure 3. Selected locations of the intersections

Although there are many factors that may affect the driver's behaviour at the a signalized intersection, this study considered only four major factors. They were, vehicle speed, distance to stop line, presence of countdown timers, and peak and off-peak time.

Data were collected on Mondays and Thursdays. The study was done for DSL and vehicle speed form the video clips taken at the above-mentioned intersections. To

determine the dilemma zones, lines were marked on the road 5 m to 5 m by 30 m. They were used to calculate the speed of each vehicle when they approached the intersection.

The recorded videos were used to calculate the average vehicle speed. Time to travel between marked lines and the stop line were determined. Through the time spent between a marked line and the stop line, and according to the distance between the marked line and the stop line, the average vehicle speed was calculated. To calculate vehicle speed accurately, the time was measured in milliseconds and video was played in slow-motion.

Results and Discussion

The summary of the results obtained by the evaluation of each intersection is shown in Table 1. From the Speed vs no of vehicles graph for peak hours, it was visible that the speed variation of intersections with CDTs was higher than that of the intersection without CDT. Further more, it was additionally observed that the red-light-running (RLR) violations are higher with the presence of a CDT.

Table 1. Summary of the results obtained by evaluation of each intersection

Name of Intersection	Count Down Timer	Peak or Off-peak	Number of Cycle	Number of Speeding Vehicle	Vehicle speed (km/h)	Dilemma Zone
Intersection A	Yes	Peak	18	49	20~55	10m-25m
		Off peak	22	51	13~45	10m-30m
Intersection B	Yes	Peak	27	49	30~60	10m-25m
		Off peak	28	47	13~45	10m-30m
Intersection C	No	Peak	18	40	12~58	15m-30m
		Off peak	20	26	20~45	15m-30m

With the presence of a CDT, vehicle speeds were higher during the peak periods and lower in the off-peak period. The opposite of that was observed without a CDT , where the off peak speeds were comparatively higher than peak period speed. This observation is illustrated in Figure 4. However the off peak speeds in the Intersection C was still not high as that of peak period in A and B. Hence, it was clear that the presence of a CDT has an overall effect on the vehicular speed during amber time.

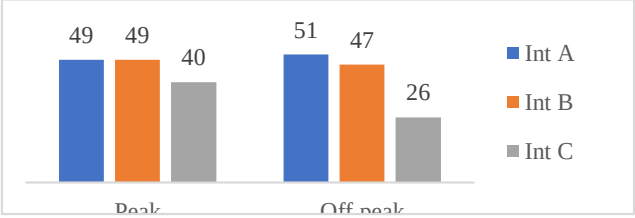

Figure 4. Summary: Number of total speeding vehicles within an hour

While the Figure 4 was developed using the total speeding vehicles within an hour, speeding vehicles per 100 signal cycles was also estimated. During peak period it was 23 and 22 for intersections with CDT and without CDT respectively. During the off-peak period it was 20 and 13 for intersections with CDT and without CDT respectively. The later was a 35% reduction.

Conclusion

This study examined driver speeding at the amber period at signalized intersections considering vehicle speed, countdown timers (CDTs), and distance to stop line (DSL). Three signalized intersections were selected around the Ratmalana area. Two intersections were operating with CDTs and the other intersection without it. Through video surveys and field surveys required data were collected during both peak periods and off peak periods. The study demonstrated that the dilemma zone of these intersections was between 15 m to 30 m from the stop line. It means, the vehicle closer at 0~15m from the stop line decides to proceed to the intersection, whereas the vehilces farther than 30m tend to stop. Further, it was observed that countdown timers could contribute to reducing red-light violations as well.

Moreover, when a CDT is available, during peak hours, vehicles are approaching with high speed during amber light than at off-peak hours. When the DSL was between 0m to 20m more drivers tend to cross the intersection, while they accelerating to higher speeds after the onset of amber. Further results of the study showed if drivers cross an intersection when the DSL was more than 30m, more of those crossings become red-light violations. Hence, it was clear that the presence of a CDT has an overall effect on the vehicular speed during amber time. However, it was debatable whether number of cycles within an hour has an affect on this number of speeding vehicles. It can be studied in future researches by incorperating that factor as well.

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Paper ID 51

Elephant Intrusion Detection, Deterrence and Warning System ("Tusker Alert")

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Abstract: The Human-Elephant Conflict (HEC) is a serious socio-economic problem in Sri Lanka. Many methods including traditional electric fence systems to novel technological approaches are being used to minimize the HEC. Each method has its limitations, complications, and disadvantages. To prevent and overcome them, a wireless sensor network-based detection system combined with a warning system, and an artificial bee sound-based deterrence system was proposed in this research. With the help of PIR and infrared sensors, intrusion can be detected, while by emitting recorded bee sound, deterrence can be accomplished. By combining those two aspects with a communication network, a warning system was developed to alarm relevant authorities such as the wildlife department, railway authority, and police stations through SMS alert system, mobile app, and warning light system while a database is also being updated regarding the intrusions which can be used for further analysis and predictions. Application of the system covers wider aspects of detecting and warning of elephant intrusions such as on village forest boundaries, rail tracks, and on roadsides (possibly on expressways) with a tested and proven result of 92% detection rate from controlled environment testing.

Keywords: Human-Elephant Conflict, Detection, Warning, Wireless Sensor Network

Introduction

The relationship between elephants and the Sri Lankan cultural value is significant and unique, hence Sri Lanka plays an important role in the conservation of Asian elephants. Sri Lanka has the highest Asian elephant density of 10% of total Asian elephants within 2% of land extent, as well as a higher human density among the regional countries Therefore, the steps were taken toward conservation and mitigation of human-elephant conflict obviously set an example for other countries too.

A. Human Elephant Conflict

The human-elephant conflict (HEC) in Sri Lanka is not a modern problem. It has been there since man started cultivation and settlements near the habitats of elephants. Mainly farming communities in dry zones and poor people in underdeveloped areas near forest boundaries suffer severely due to elephant attacks. crop raiding, village raiding and destroying houses to find salt and rice, sudden attacks on the roads are the main types of attacks. When considering the deaths of elephants due to human activities, between 2005 and 2010 the total number of 1154 elephants had been killed where 574 were gunshots. 105 deaths caused by electrocution and 90 were caused by train accidents. (Fernando, et al., 2011) later from 2010-2018, 69 more elephants were dead due to train accidents. (Fernando & Usgoda arachchi, 2018). Annually about 71 human deaths are recorded due to elephant attacks and many

more damages on the property. According to (Santiapillai, et al., 2010) most of the crop raids were carried out at nighttime between 1900-0400hrs where villagers are totally unaware of elephant intrusions even by breaking electrical fences and entering fields. When considering train accidents, many were occurred due to the unawareness of the presence of elephants on the railway tracks mostly at night.

Many of the farming communities have been ignored or beyond the reach of the department of wildlife conservation. Farmers in such areas are therefore left with the responsibility of defending their crops, goods, and houses from wild elephants by themselves by shooting or poisoning while keeping trust in the electric fence without even knowing the condition of it. Therefore, there is a need to find localizes detection deterrent and warning systems that are not only simple in application but also affordable and long-lasting to deter elephants.

B. Literature Review

Various methods and systems had been developed throughout the years to address the HEC. Electric fence act as both physical as well as a psychological barrier to elephants. But it did not eliminate the issue nor offer a stand-alone solution for HEC. (Gunaratne & Premarathne, 2006) . Intrusion detection and alerting system for electric fences (eleAlert) were designed and implemented by (Wijesinghe, et al., 2011). However, eleAlert system consists of a major limitation of the physical access to the system for repairing and maintenance after an intrusion. (Fernando et al,2012) presented a method to track elephants using radio collars to get GPS locations of elephants (Fernando et al,2012) has proposed a system for detecting elephants using RFID system. It has a limitation of short-range detection and it has low update rate of the locations. Moving to systems with visual and image processing approach, (Sugumar & Jayaparvathy, 2014) introduced a system to recognize elephant intrusion along the forest borders with the use of real-time image capturing. A vision-based system has been developed by (Dua et al,2015) with the aid of a video camera with 85% detection rate. the detection system is developed by (Ramesh, et al,.2017) which used to identify elephants using image processing. These methods dynamically learns from the trained images with different backgrounds, distances and light conditions. (Ramesh, et al., 2017). Vision-based systems had limitations with the light condition, camera angle and field of vision. to detect elephants they often need reference images to identify the object. A method that uses geophones to sense the vibrations of elephants were presented by (Suganthi, et al., 2018) and (Nakandala, et al., 2014) developed a WSN system that acts as a virtual boundary around a village using PIR sensors and IR sensors. Vibration sensors, geophones, and seismic sensors would not be effective near railway tracks since the train itself generates a considerable amount of vibration around the area which might lead to false identification, further the vibration sensors placed underground, and their wiring could be damaged and maintenance would be difficult. A research conducted in Laikipia country, Kenya by (Graham, et al.,2012) came up with a conclusion that cell phones can enhance communication and decrease human-elephant conflict with a place there is excellent mobile coverage. A research has been conducted in Udawalawe National park by using a disturbed Asian honeybee buzzing sound, elephants responded by moving considerably additional aloof from their resting areas. Further (King, et al., 2007) states that elephants are not only moving away from buzzing bee sounds with unique low frequency rumble that warns other elephants in the area to retreat

from the threat (King, et al., 2010). This important finding of the fear of elephants to buzzing bee sound is used in the proposed system to deter and drive away from the elephants.

C. Significance of Research

Considering the facts, the main reason which causes such damage has been found out as the unawareness of elephant intrusions to human habitats and railway tracks. Thus, the need for an improved integrated system for detection, early warning, and deterrence with a reliable data acquisition method has emerged.

If an early warning could be provided, relevant authorities could take action on elephants while people in affected areas could avoid direct confrontations with elephants. Motivated by this idea, the designed system will serve to minimize the HEC in rural areas and railway tracks by detecting and warning of elephant intrusions while deterring and driving them away from vicinities until long term strategic plans and habitat management, enrichment policies establish to overcome HEC completely.

Methodology and Approach

A. Modular Design

Design contains 4 modules.

i. Detection module- Dual IR beam detectors 100m range and PIR sensor 12m range.
ii. Deterrence module - contain 8ohm 4W speakers and mp3 module to play buzzing sound of bees.
iii. Warning and DAQ module- signal lights connected by NRF24 RF module for wireless communication up to 1 km, GSM module to generate SMS and GPRS data to ThingSpeak data base platform which can be accessed by ThingView open source app.
iv. Power module – Operation 3A and standby 1mA is required. The system is required to work at least 24 hours without solar charging. Hence,12V 7Ah 20HR Sealed Lead Acid battery,20W solar panel with 14.5V 10A Solar charger controller is used.

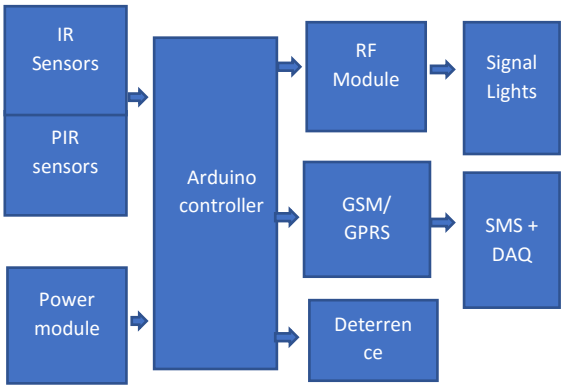

Figure 1. Modular design of system

B. Operation of the System

Primary detection was done by the Dual-beam IR sensors up to 100m. If both IR sensors set HIGH for 1.5 seconds delay (set to tackle the average walking speed of an elephant), Then the signal modules activated by RF signal until they are turned off by the observers. (In case of street signal lights, the signal modules will be activated with reference to the PIR Sensors). Simultaneously, the GSM module will execute AT commands for SMS and GPRS databases. When the Database gets updated it will notify on the mobile application.

On all occasions, the deterrence module is activated with the PIR signal to repel elephants from the nodes in order to protect the nodes. On railroads and roadsides, the deterrence module will be associated with the IR signal too. On Implementations to village boundaries, the deterrence module will not be activated

with the IR signals (elephants may deter and run inward).

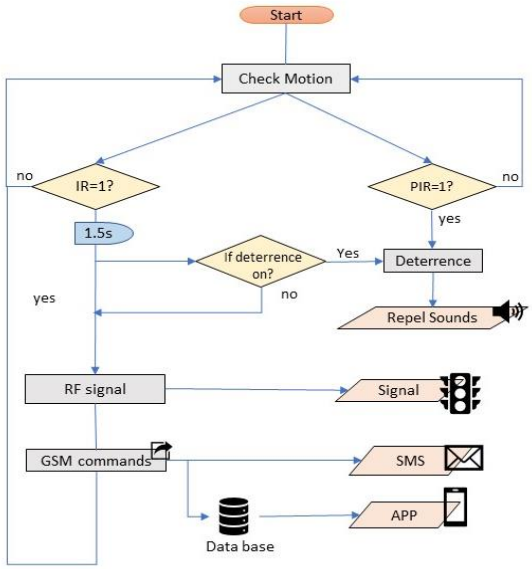

Figure 2. Operation of system

C. *Detection Nodes Optimization*

In optimizing the detection module, we have assumed that juvenile and baby elephants do not move alone without herd and if moved, the threat from baby elephants is minimum. Based on that assumption the optimized height of sensor placement is done for the worse case of detecting an intrusion of an isolated juvenile male elephant

According to (Chelliya Arivazhagan and Raman Sukumar, 2008) the mean Height for male juveniles 208 cm and for female juveniles is 229.7 cm. According to (Fred Curt and Janak C. Kumarasinghe, 1998) 200cm – 240cm for ages 10-20 years for Male elephants and 182- 215cm for juvenile female elephants. After measuring heights of 4 juvenile male elephants a mean height value of 212.5 cm obtained and compared with previous references. A general height value based on our assumptions was taken as 210cm by keeping a factor of safety 1.0. hence the topmost sensor placed at 210 cm and a lower sensor placed at 160cm, keeping 50cm body detection space.

A horizontal distance of 50m was marked along the elephant moving the path and marked spots. Then using video footage time taken to move was measured for randomly selected samples and hence speed is calculated. The average speed of an elephant of walking normal phase was found out to be 1.5 ms-1 with a range from 0.8 ms^{-1} – 2.1 ms^{-1}.

Ambiguates of references with the measured speed showed the unpredictability of the speed of individual elephant. Therefore, the maximum limit of (6.9 ms-1) range was set in the sensor so that any movement less than that could be detectable to the sensor. Keeping a factor of safety of 4.6

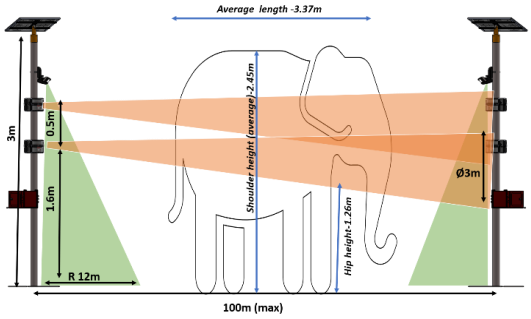

Figure 3. Dimensions of Detection system

D. *Warning Module*

Warning messages were supposed to be issued about elephant intrusions for its users. 4 types of users were targeted.

i. Users with normal mobile phones
ii. Users with Smart mobile phones
iii. Users with the Mobile application installed phones with GPRS
iv. Users who don't have mobile phones

To address all 4 users 3 variations of warning methods were used.

i. Alert SMS system with a google map link
ii. Online database and Mobile application
iii. Warning Light module

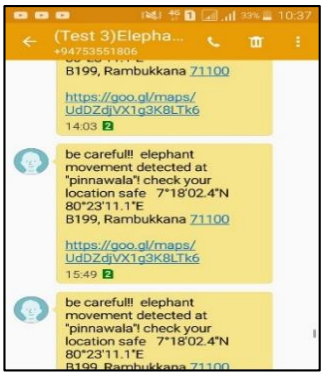

Figure 4. SMS warning with google map link

Alert SMS with google map link will notify the normal phone users as well as smartphone users. These users can directly check the time and location via google map link or SMS itself. This warning method was tested along with the Test 3a. The current module only uses up to 5 numbers and

could be maximized if combined with an 'SMS Gateway'. SMS could be sent to respective forest officials, police stations, railway stations or any other relevant authority and

the warning light module using RF signals has a range of 1000m. These modules can be implemented on railway tracks and roadsides as signal lights as well as in houses and assembly places to notify users about elephant intrusions. The designed module lights up until the user turns off the switch hence getting an acknowledgment from the user.

E. Monitoring Center

The monitoring centre of the tusker alert system is developed using the ThingSpeak IoT platform. Data is sent using HTTP POST requests using the GPRS module to the ThingSpeak channel. The saved data on the IoT data base could be extracted as .CSV .XML or .JSON file types for further analysis. Using MS Excel extracted data was analyzed and visualized. This channel further allows analysis and visualization of the recorded data using MATLAB

The IoT channel is accessible through mobile app named ThingView and it was customized to view all the fields of the channel in graphical form. ThingView mobile app allow several analytical and visualization functions such as time pre-set analysis, custom comparisons, etc.

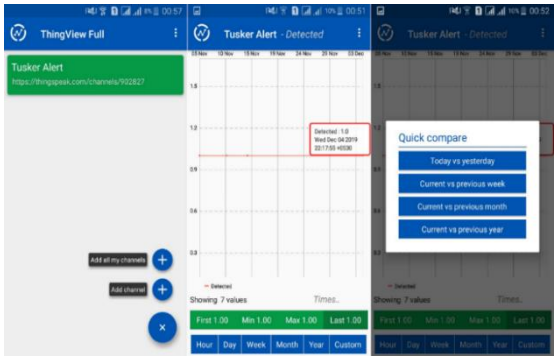

Figure 4. Thing view data monitoring app

F. Safety of System

The safety of the system was considered in 3 aspects. elephants, human and harsh environmental conditions

1) To prevent damage from elephants: the following methods are suggested when implementing the system in the real world. Driveaway elephants by emitting deterrence sound at 12 m. Using bio fences such as short lime vegetations around the system for 10m radius and embedding the system into a solid concrete structure.

2) To prevent the system from human threats: such as thieves following options followed; Implanting control box at 2.7m above ground beyond the reach of an average human. Using sensor tamper output signal and safety switch at the control box to generate a security alarm SMS on unauthorized breaching and using a community-based approach for awareness on maintaining and inspecting the system.

3) To prevent from harsh Environmental conditions: International protection rated sensors were used in the system. Dual-beam IR sensors (IP66) were protected from total dust ingress, protected from high-pressure water jets from any direction and limited ingress. PIR sensors

(IP44) protected from tools and small wires greater than 1 millimetre and protected from water spray from any direction. The validity of the ratings was also been tested by keeping the apparatus under heavy rain for 3 hours and no moisture was found inside. Embedding into a concrete structure in real world implementation would also increase the protection. Clearing the overhead trees and branches to ensure the maximum performance of the solar panels.

Test and results

This system was subjected to 4 tests. Node placement varied from 9m to 30m while nominal distance was stated as 100m

A. Test 1 – Detecting vehicles at KDU

Test1 was done as a control test with vehicles and a 100% detection rate of vehicles taller than 2m was obtained at KDU. Small trucks, trucks, buses, and lories are taller than 2.1m hence they are detectable while car bikes and vans are at undetectable height.

B. Test 2a and 2b – Elephant detection at Dehiwala Zoo

These tests were done using 6 sample elephants in the Dehiwala zoo. Test was conducted by keeping detection nodes 30 m apart and when elephant walk through.

Table 1. Sample Characteristics for Test 2

Name	**Number of tests**	**Detected**	**Detected rate %**
Namali	2	1	50
Madhavi	3	3	100
Bandula	3	3	100
Total	**8**	**7**	**-**
Average	**-**	**-**	**87.5%**

1) Test 2a: Individual elephant detection was tested at Dehiwala Zoo and a 95.45% detection rate was obtained.

Table 2. Results of Test 2a

Name	**Number of tests**	**Detected**	**Detected rate %**
Devi	2	2	100%
Khema	4	4	100%
Indi	2	2	100%
Namali	6	6	100%
Madhavi	8	7	87.5%
Total	**22**	**21**	**95.45%**

2) Test 2b: Done with an inclined path of 12° to simulate a situation of inclined railway crossing path. 87.5% of the detection rate was observed. It must be noted that test 2b was done using a sample of 3 elephants and for 8 times. Hence this result is not significantly accurate

Table 3. Results of Test 2b

Name	**Gender**	**Age**	**Shoulder height**
Bandula	M	52	297 cm
Devi	F	30	245 cm
Khema	F	36	242 cm
Indi	F	32	235 cm
Namali	F	17	230 cm
Madhavi	F	14	225 cm
Average			245.7 cm

C. Test 3 – Detecting Elephants & Herds at Pinnawala Elephant Orphanage

Test 3 was done at Pinnawala Elephant Orphanage. There a more realistic elephant behavior could be observed. Individuals, Adult Herds, and Herds with Juvenile elephants were present.

Table 4. Sample Characteristics for Test 3

Age (years)	Mean Height(cm)	Male	Female	Total
10-20	210	17	13	30
20-40	235	2	22	24
>40	240	3	4	7
Total	**220**	**22**	**39**	**61**

Table 5. Results of Test 3

Type	Number of Events	detected	rate%
Single	14	12	85.7%
Adult Herd	6	6	100%
Juveniles herd	8	8	100%
Total	**28**	**26**	**92.85%**

92.85% of Detection rate was observed with 100% Herd detectability.

Figure 4. Test 2a at Dehivala zoo. (Prototype is on right corner)

PIR detection within a 12m range of sensor nodes was also tested for activation of Deterrence. (But Deterrence sounds did not activate due to uncertainty, safety and reactions) there a 100% Detection for deterrence module also been observed.

To get a general idea of the performance of the Detection Module, a General Detection Rate is calculated (excluding test 1)

$$General\ Detection\ Rate = \frac{\boldsymbol{Sum\ of\ Result\ of\ (Test2a, 2b\&3a)}}{\boldsymbol{number\ of\ tests}}$$

General Detection rate of 91.93% was achieved with the primary detection system.

Application and Implementation

The designed system for detecting deterring and warning of elephant intrusions has a wider scope of applications where Human-Elephant Conflict is possible. Such identified applications are,

i. On Village Forest boundaries
ii. On elephant corridors at railway tracks where train elephant collisions are possible.
iii. On elephant corridors at roadsides where elephant presence is frequent

On each application, the system needs to undergo slight adjustments according to the terrain.

A. On Village Forest Boundaries.

On implementing the system in village boundaries following considerations need to be followed. Under-layer vegetation should be cleared and planted with plants like orange, lime or lemon which elephants have no appetite. Then the WSN transceiver nodes need to be implemented strategically behind the electric fence. Each house is equipped with an alarm system and each villager is getting an SMS or warning to the smartphone app. Centralized node with deterrence and warning modules need to be strategically placed in the boundary area so that any unnoticed person can be warned, and elephants can be deterred away. This centralized node could be used as a base station and all the detection signals from detector nodes could be collected in RF and converted into a GSM signal. (This will eliminate the GSM signal issues).

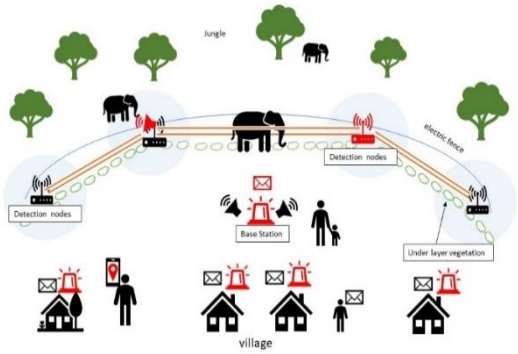

Figure 4. Implementation on village forest boundaries

B. On Railway Tracks and Roadsides

The receiver and transmitter modules are places parallel to the track (2-5m away). The maximum line of sight distance is 100 m. The signal lighting system is placed 1km away from the corridor and this distance can be increased using directional antennas to transmit RF signals. When an elephant passes through the sensors an alert SMS will generate as well as an RF signal sends to the signalling modules simultaneously the deterrence modules are activated. If an elephant reaches or moves beyond the limits along the track a special caution alarm will be generated with the signal. The warning modules can be placed in the engine room of the train if the train comes to the range of RF signals automatic warning will be given to the driver.

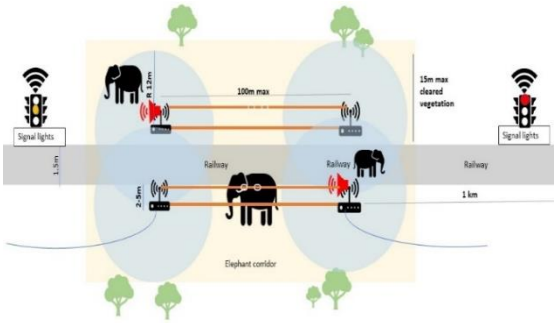

Figure 5. Implementation on Railway tracks/Roadsides

On implementing roadsides, the sensor placement is like that of flat/inclined rail tracks, but in case of a longer elephant corridor, the number of transceiver nodes would be increased. The vehicle drivers are alerted using warning signals as well as through the mobile application.

Future Improvements

Future improvements for this system are suggested as to carry out a pilot project with the wild elephant in a threatened area. Designing a circuit integrating all components (PCB) for commercial production. Integrating a SMS gateway portal for bulk SMS with subscriber options and Develop the prototype of the app. Integrate more IR beam sensor arrays and enhancing PIR to develop a Fuzzy logic controller to identify even juvenile elephants more accurately. Develop the monitoring IoT platform for better analysis and visualization performances. This design is already updating its data to a ThingSpeak cloud database in the MATLAB environment. By analysing the collected data for a long time and by identifying behavioural patterns of elephants, it is possible to manipulate this data for better visualization options as well as to implement a prediction algorithm. Finally providing opensource system access to the community for its developments and improvements.

Conclusion

Human elephant conflict is known to be a major socio-economic problem in Sri Lanka causing fatal damage for both humans and elephants. Protecting the lives and properties of people as well as conserving elephants was the focus of this project. Thus, the elephant intrusion Detection Deterrence and Warning system named “Tusker Alert” was successfully designed as a possible effective solution to minimize HEC. The design is Solar powered and uses IP (Ingress Protection) rated IR beam and PIR sensors for detection and GSM/GPRS for alerting along with RF warning light system used for warning. Buzzing bee sound and Elephant rumbles were used to

deter and drive away from the elephants. The detection system was tested and observed a general detection rate of 91.9%. The application of implementation was enhanced to a wider range of applications such as for village boundaries, for railways and for the roadsides. This system is further enhanced by adding an IoT Things Speak database for monitoring functions of the node and a mobile application prototype to warn the users about elephant intrusions. Database and apps are suggested to be improved up to an advanced visualization and prediction algorithm along with the other future works. Finally, a possible solution for minimizing human-elephant conflict in rural areas of Sri Lanka and as well as an aid to the DWC and Railway department efforts on minimizing train elephant collisions were provided as the outcome of this project.

Acknowledgment

We express our sincere gratitude to the support rendered by Department of Mechanical Engineering of KDU,to the staff of National zoological garden Dehiwala and Pinnawala elephant orphanage and to our Squadron commanders, troop commanders, friends and comrades for supporting us.

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Paper ID 82

Design and Fabrication of an Automatic Ruler Printing Machine

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Abstract: Automation has been popular among most manufacturing and production systems due to improved efficiency, high production rates and low wastage. The project was focused on Designing and Fabrication of an Automated Ruler Printing Machine for stationary item manufacturing industry. The main objective of this research was to fully automate the twelve-inch ruler printing mechanism which was currently based on manual production methods. Due to the drawbacks of existing ruler printing processes of Sri Lanka, the mechanism was proposed to be automated in order to minimize consumption of human labor and time while improving safety, production hours and production rates of the manufacturing process. The research was focused on automating basic functions of ruler printing process such as loading, unloading, cleaning, printing and packing to reduce the human involvement in the process. Thus, the proposed method basically focusses on rotary indexing mechanism to synchronize all the functions of the manufacturing process to support the continuous loading and unloading of rulers. It was designed to increase the rate of production by printing four rulers at once while saving the cost of labor by reducing human involvement by automating main functions of the manufacturing process.

The research was focused on introducing online packing section and inbuilt ink drying mechanism to reduce the work in process (WIP) and lead times during production while improving accuracy and efficiency of the process by using a compact design.

Keywords: automated ruler printing machine, screen printing, loading, unloading

Introduction

Most of the stationary item manufacturing companies in Sri Lanka uses manual / semi-automated methods to print rulers. Normally, semi-automated screen-printing machine which use to print twelve inch rulers require the engagement of two employees and packing process is done separately with the involvement of another employee. Due to the manual interference, some drawbacks have identified which affects the production speed, accuracy, efficiency and production time. Loading, unloading and handling of rulers consumes much time compared to printing time. Another issue related to the process is that rulers need to be kept for drying about 20 minutes which increase the manufacturing lead time of printed rulers. While these issues persists, increasing production can only be done with extra shifts, concerning the safety of the workers, this would be limited to day shifts only. To overcome the drawbacks, semi-automated screen-printing machine is to be replaced with a fully automated screen-printing machine without the interference of the human. The aim of this research is to design and implement an automated ruler printing machine for stationary item manufacturing industry to improve the current productivity and to overcome the drawbacks of the existing semi-automatic

system. This proposed method spans from designing a rotary indexing-based ruler printing machines with a conveyor, fabricating and developing control system to commissioning of machine to the production line.

Methodology

The steps of the current semi-automated mechanism of twelve-inch printing machine can be shown as in the following flow chart.

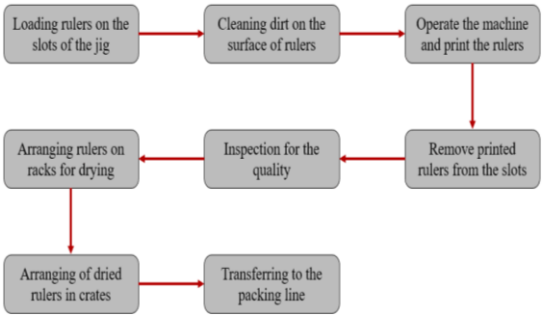

Figure 1. Flow Chart of Existing Process

The new system was proposed to overcome drawbacks of current system and main steps were identified to develop methodology associated with the proposed system.

The main focus of this research was tended towards automating loading, cleaning, printing and unloading mechanisms since those were observed as the key functions of the entire process. For this, a rotary indexing mechanism was proposed since it supports continuous feeding of rulers and unloading, compactness of the design, simplicity and cost effectiveness of the mechanism. In addition, separate automated mechanisms were proposed to be implemented for loading, cleaning, printing, unloading and conveying process.

As the first step unprinted rulers which were taken directly from the molding process are stacked on the loading unit by the machine operator. Here it was proposed to use two separate loading units to load onto two different stations of the rotary bed. Printing unit was proposed to be implemented at the third station of the rotary bed for the printing process and it was identified as the bottleneck of the manufacturing process. Moreover, the printing rate and other essential parameters for handling the printing will be set by using a Human Machine Interface operated by the machine operator.

At the final station, it was proposed to implement the unloading mechanism which will be introduced to the conveying process. Based on the sensor inputs from the attached sensors the respective actuators will be manipulated by the computerized control system (PLC's, microcontrollers) to release the loaded rulers, clean, print, and unload the printed rulers on to a conveyor for the drying process and then convey the rulers to the online packing section.

The machine as designed to interrupt by any safety measuring sensor signal or emergency stops that were performed by the machine operator. The whole system was proposed to be programmed using microcontrollers and the feedback alarms will be generated based on the pre-programmed working conditions and safety measures. A computerized system will be used to hold the feedback of the production data. Finally, the printed rulers will transfer through conveyor with drying units which installed on the conveyor to dry wet ink on the printed rulers and at the end they will be packed by the employees working at the online packing section.

Design

The machine was designed to perform the task of fully automatic ruler printing mechanism. Designing was done with the SolidWorks software and major concerns of the design tends towards adjusting mechanisms and manufacturing flexibility. Manual adjustments were added during designing to overcome the practical

problems arise during production and maintenance.

Another area covered in this design was manufacturability aspects. All the parts were designed to be manufactured with the aid of available technology to overcome the unnecessary machining costs and maintenance costs. Methods of maintenance and repair were considered since the machine was planned to be used for long run and to increase the productivity of the process.

The design of Automatic Ruler Printing Machine was developed by dividing into two main parts.

i. Rotary Bed
ii. Conveyor with Drying

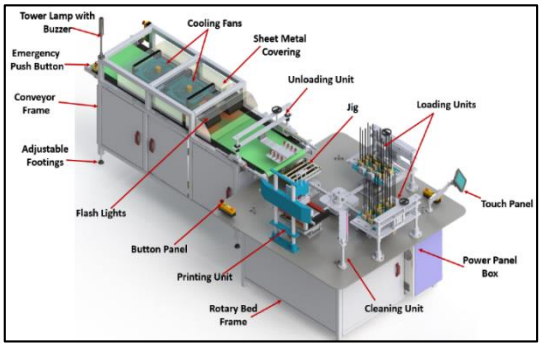

Figure 2. Complete 3D Model of the Machine

A. *Rotary Bed*

Rotary bed can be illustrated as the main functional unit of the machine and it was designed by using the Rotary Indexing Mechanism in order to link each and every step of the ruler printing process.

The unit includes a table with a rotating jig arrangement which was used to hold the unprinted rulers. As in a typical rotary indexing mechanism, stations were fixed to the table. There were four stations fixed in the machine. They are;

i. Loading Station
ii. Cleaning Station
iii. Printing Station
iii. Unloading Station

In the rotary bed, jigs were used as the working carriers and design was done to print four rulers at once. Jig comprises of square shaped slots to mount a sensor to sense the presence of the ruler before printing. The design was optimized with four key bars holding the four jigs each at a 90-degree angle. A nylon roller assembly was designed to be mounted under the key bar as a support to withstand the tension of key bar while printing. Since whole design was based on rotary indexing mechanism bearings were used for smooth and long-term functionality. Total axial load was calculeted inorder to select the appropriate bearings. Here a bearing holder was used to hold two roller bearings and one thrust bearing.

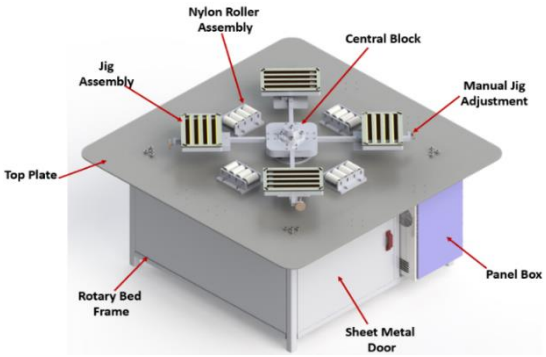

Figure 3. Rotary Bed

Manual adjustments were used where ever it necessary to overcome the practical issues. The whole rotating jig arrangement was driven by the power transferred by the main shaft. The shaft was connected to the gear box and keyway was used to couple the gearbox to the shaft. Since jigs had to be stopped at precise locations a servo motor was used and by using its feedback, jig arrangement set to rotated in 90-degree angles in predetermined intervals.

To estimate the power required for the servo motor, calculations were done to measure power required to overcome the frictional torque and power required at maximum angualr velocity.

Power required to overcome the friction between shaft and trust bearing was calculated using the equations (1) and (2),

$$M = \frac{2}{3} * \mu_k * F_{Load} * \frac{{R_o}^3 - {R_i}^3}{{R_o}^2 - {R_i}^2}$$

μ_k=0.6 (steel) (1)

$M = 80.3Nm$

P= $\tau\omega$

P= 84W

Power required at maximum angular velocity calculated using the graph.

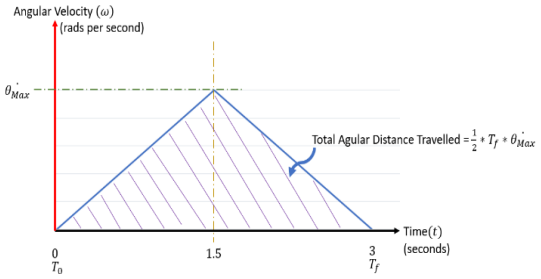

Figure 3. Graph of power required at maimum angular velocity

$$\frac{\pi}{2} = \frac{1}{2} * 3 * \dot{\theta}_{Max} \quad (2)$$

$\dot{\theta}_{Max} = \frac{\pi}{3}$, $P = \tau_{Assembly} \times \omega$

$P = 19.5$W

Accordingly, total power required for the servo motor of the rotary bed was 103.5W.

The first and second station of the machine was designed to be used for loading of twelve-inch rulers into slots of the jig. The loading mechanism was designed to feed rulers automatically to the jig and due to the complexity of the design, unit was designed to load two rulers at first station and other two at second station. Guiding rods were placed to guide rulers smoothly on the slot of the jig and they have the ability of loading 150-160 unprinted rulers at once. Manual labor was required to refill the slots when the stack was running low and time hich takes to refill the slots was calculated the refilling frequency as 30-40 minutes. For the gripping and releasing of rulers, pneumatic cylinders were used, and a manual adjustment was used to do fine adjustments of the unit.

Third station of the rotary bed was used for printing. Printing on the rulers was the most crucial since if there any misalignment in the machine, the quality of the print will be lost. Rubber squeegee was used to uniformly distribute ink on the surface of the silk screen where blade was placed to remove excess ink on the sides of the screen. This unit was based on two axis movement principle and linear bearings with a guide rail and pneumatic cylinder was used for the horizontal motion of the printing head. For the vertical motion two compact cylinders were placed and two bearing shafts were used for smooth motion. In an occasion where one ruler is not present on the jig, the printing cannot be done as it will damage the silk screen which will result the blots in the print. This will lead to replace the silk screen which consumes more time causing production loss. Thus, the unit was designed to eliminate these cases by rotating another round to fill the missing ruler without being printed. Therefore, to stop the damages to silk screen, fiber optic sensors were used to check the availability of the rulers before arriving the printing station.

Fourth station of the machine was designed to unload the printed rulers from the jig and transfer them to conveyor for drying process. At this station unloading was performed automatically and the entire unloading unit was designed to be operated automatically with the power of pneumatics. The unloading unit can be actuated through suction-based mechanism using eight suction pads, two for each printed ruler. Suction pads were mounted on the unprinted area since unit was designed to suck the printed rulers with wet ink. Unloading unit was designed as separate unit to be mounted on the conveyor frame for easy manufacturing and maintenance activities. This has a

combination of vertical and horizontal movements to achieve the function of pick and place the printed rulers and the unit was designed to match the speed of the printing.

To remove the dust particles which are stuck on the surface of the unprinted rulers during the molding process a cleaning unit was mounted in between loading and printing station. In this design a combination of wiping and air cleaning method was employed to remove the dust particles on the unprinted rulers and to ensure no dust particle retains on the surface as they reach to the silk screen of screen-printing unit. By using a compressed air flow and a piece of sponge all the dust particles will be removed from the ruler surface while the jig is rotating. This cleaning process was designed to cut down the damage, wear and the frequency of replacing the silk screen of printing unit which helps to keep the production rates constant and efficient. This design was done to achieve a profitable production rate and to improve efficiency of the process by replacing the manual dust removing method.

B. *Conveyor*

Conveying process of this model was designed to be used as a bridge between unloading and packing mechanism of the ruler printing machine. The conveyor was designed with heat resistant belt which will support the dry the ink of printed rulers and introduce them to the online packing process. Unloading unit was attached on one side of the conveyor and at the other end packing process will be done continuously.

Conveyor was designed with a belt driven mechanism with all tension adjustment mechanisms on it. Normally conveyor was designed to be continuously at running mode which is synchronized with the speed of the printing unit. The conveyor was created as an independent unit which was attached to the ruler printing machine for easy layout changing and moving and all the parts are designed for easy maintenance and replacements.

The new model was equiped with an inbuilt drying unit which mounted on the conveyor which will directly lead to online packing mechanism. In this design, a pair of Flood Lights and a pair of Industrial Cooling Fans were used separately, and they were mounted on the top of the conveyor by using a profile bar frame. The flood lights with a power of 500W were covered with a sheet metal shield to improve safety and to minimize the power loss of the unit. A sheet metal covering was used to cover Cooling Fans and mounted separately on the conveyor frame.

Materials were selected according to the requirement of the design and considered about all the safety issues, maintenance and manufacturing factors. The design includes all the security measures including emergency buttons, button panel box and a tower lamp with buzzer. A touch panel was designed to be mounted on the machine in order to build a human machine interface.

C. *Control System*

As the control structure of the Automated Ruler Printing Machine, Programmable Logic Controller (PLC) based control system was used along with the sensor inputs, electrical and pneumatic actuators. Human Machine Interface (HMI) was used to input data to the PLC and display data.

The basic structure of the control system can be illustrated as follows.

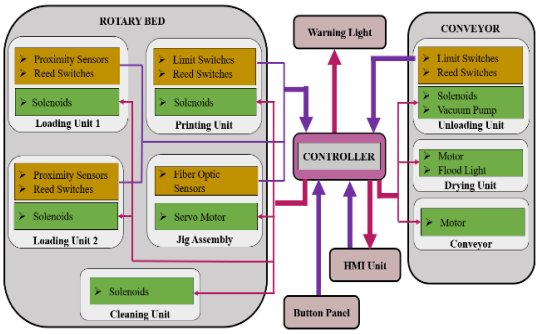

Figure 4. Structure of the Control System

As the microcontroller of the Automatic Ruler Printing Machine, a PLC was used with PLC programming language ladder logic. HMI was used to input data to the PLC and display data. Several sensors such as fiber optics and proximity sensors were used throughout the machine for required phases of the machine.

Most of the actuators were based on the pneumatics and for this several solenoids, pneumatic fittings, suction pads and vacuum pumps were used.

Results and Discussion

The main aim of this project was to fully automate the function of twelve-inch ruler printing process and most of the project objectives were achieved by doing alterations throughout the project. As mentioned, rotary indexing mechanism was used with four stations and for this design a key bar arrangement was used eliminating the difficulties of using a solid rotary disc. Loading, cleaning, printing and unloading is done at separate stations and all the sub assembly units were designed as separate units for easy fabrication and maintenance activities.

Since some of the basic functions were crucial, they were tested using prototypes prior to final design. By this most of the problems were overcame. By introducing online packing for rulers by using a conveying process, the reduction of work in process and lead times were achieved. Inbuilt drying unit also taken a prominent place since it reduced the dying time and improve production rates during the ruler printing process.

Calculations and simulations were done to optimize the design and analysed the results obtained by the fully automated machine and existing semi-automated ruler printing machine in order to achieve project objectives.

The bottle neck of the process was identified as the time taken to dry the printed rulers , the manual process involved a free air drying technique which on average consumed 15 minutes. The problem of drying time lead to increase in work in progress and lower production rates the use of UV based ink allowed the drying time to be improved to an exposure time of 5 seconds on the running conveyor which in turn improved the production rate.

Comparison for the production rates of prevailing semi automated machine and fully automated machine was done by taking production data for day shift. Accordingly, it was observed that approximately 390 rulers can be produced per hour by using semi automated machine leading approximate production of rulers as 3500 per day. Due to the poor safely issues, production of rulers from existing machine was done only at day time.

By automating the process, it was able to double the production rate by minimizing the drawbacks of the current process. The production of rulers via fully automated machine can be done in both day and night continuously as two shifts due to the improvement of the safety features and production rate was increased by reducing drying time. Accordingly, it was observed that approximately 780 rulers can be produced per hour leading 14000 rulers per day as production can be done in both day and night.

Accordingly, camparison of rate of production of semi automated and fully automated ruler printing machine can be shown as follows.

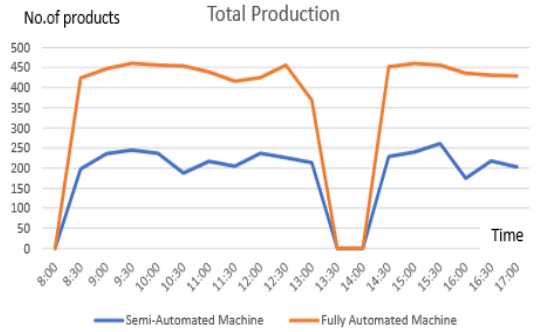

Figure 5. Comparison of Rate of Production

The technique of UV lighting for drying allowed to achieve the expected production rates, further research is required to analyse the cost effectiveness of the process considering the cost for electricity for the high power UV lamp.

The use of high precision cam indexing servo driven gear box allows feedback based deceleration to stop the jig at 90 degree increment of shat angle. This feature combined with sponge based wiping and compressed air supply allows removal of dirt from the unprinted ruler surface with allowed quality print on the surface leading to less defects. Following comparison shows the defect reduction.

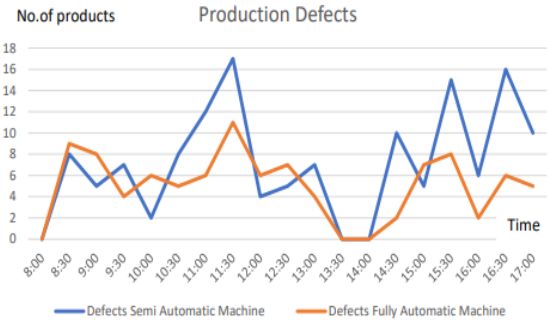

Figure 6. Comparison of Production Defects

Accordingly, by fully automating the ruler printing process, it was able to minimize the production of defects and other drawbacks of the current ruler manufacturing process and improve the production rates which will increase the ability to cope up with customer demand.

Conclusion

The Automated ruler Printing Machine was designed to overcome the drawbacks of the existing ruler printing process and to increase the productivity. In the design, main focus was to automate the printing process and support the online packing function. As identified in the methodology, worker involvement was reduced by introducing mechanisms to Loading, Cleaning, Printing and Unloading.

First critical function was the loading station with the requirement of four rulers printed at once, two loading stations were used to simplify the loading operation, although this improves the process further designing could ensure the loading of all the four rulers from the same loading station which would improve the overall efficiency of production.

The production of the semi automatic machine was limited to daytime shifts only due to the safety risk involved as operator hand was involved to load and unload the rulers with the new design safety was improved by the use of a loading tray, its is essential to improve the design further to prevent any hazards based on moving parts and contact of human operator further research with qualitative measures would prove improved safety. The defects were reduced based on precision alignment and improved cleaning, end product defects were based on human operator judgement to distinguish defective products, research continued on identifying defects based on scientific method would lead to improvements in quality such as computer vision to compare the products.

Another step taken to optimize the design was, adding adjustments for mechanical mechanisms. Even with the calculations, some practical scenarios cannot be

addressed. For the machine, most of the components were selected based on calculations and referring to manufacture's catalogs, suitable components were selected. But in some scenarios, available components were used as per the company's preference.

Calculations and simulation results were used to confirm their suitability. This machine was designed for the long run of the company with improved productivity, efficiency and safety, by correct utilization of the machine, expected output can be obtained.

Major problem identified for further research is to optimize the drying time based on humidity & temperature to prevent sticking of the printed rulers to polythene packaging material , additional data collection method is required to be developed to inspect the sticky surface of the ruler with the polythene to further improve quality of production.

Acknowledgment

Special thanks goes to staff of Mechanical Engineering Department, Faculty of Engineering of General Sir John Kotelawala Defence University,Ratmalana, Sri Lanka and Atlas Axillia Co.(Pvt) Ltd, Sri Lanka for providing valuable support, facilities and funds for the research work.

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Paper ID 126

• Software Interface to Log High-Speed Data Acquired from a Stress-Strain Measuring System

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Abstract: The jumping performance of a frog is determined by several characteristics of the frog. A system is developed to record the dynamic reaction force response of a striped marsh frog inserted on a platform in the propulsion phase of the jumping cycle. To record dynamic response, simultaneous data acquisition and high-speed data recording is necessary. This research paper discusses how the development of the software interface to log high-speed data is done using C. The primary objective of the system is to collect data simultaneously in a high-speed data rate. ADS1299 Analogue to Digital Converters (ADCs) is used and coupled with three strain gauges attached to the three axes of the platform. The ADC sampling is controlled by a microcontroller, and data is transferred to the PC using the serial port. The Graphical User Interface (GUI) of the software application is capable of reading, saving, retrieving, and plotting data. Besides, the software is capable of static load-based calibration and taring. The developed system is capable of recording the dynamic ground force response of an object inserted on the platform using the developed software interface. The primary objective, collecting data simultaneously at high speed, is achieved with a maximum data rate of 980 SPS. An additional option is given to calculate the jumping angle of the frog using the resultant reaction force.

Keywords: High-speed data Acquisition, Simultaneous sampling, Force platform

Introduction

Observing animal behaviors is interesting and modeling those leads to new knowledge. This project is based on measuring dynamic performance of a striped marsh frog. A jumping cycle of a frog can be divided into four sub-phases: propulsion, flight, landing and recovery. Variables characteriz- ing the propulsive phase are take-off velocity, ground reaction forces, and jumping distance. The average weight of a stripped marsh frog is ranging in from 2.9 g to 38.4 g. Stripped marsh frogs take off by extending their hindlimbs and use forelimbs for landing [1].

A force platform design for measuring jumping performance is consisted of a circular acrylic top mounted on a L-shaped double-cantilever brass beam which is fixed to an acrylic bottom plate [2]. The frog extending its hindlimbs on the force platform while take off and vertical, horizontal and lateral ground reaction forces exerted on the platform is measured simultaneously.

Methodology

The designed platform is capable of measuring the vertical, horizontal and lateral ground reaction forces of a jumping frog in propulsion phase. The data rate of the designed system is sufficient to capture dynamic performance of the frog. A high-speed cinematography camera is only capable of capturing at a rate of 500 frames per second [2]. So better results can be obtained by the developed system. One

main objective of the system is to interface three strain gauges for high speed, simultaneous data acquisition.

An Analogue to Digital Converter (ADC) ADS1229 is used in order to achieve high speed data acquisition. Characteristics of the ADC are data rate of 250 SPS to 16 kSPS, 8 chan- nelled, simultaneous data acquisition with high resolution (24 Bits) and offered with built-in oscillator and I2C-compatible serial interface. This ADC (ADS1299) is used in applications like Electroencephalogram (EEG), sleep study monitoring and evoked audio potential studies [3]. ATMega 32u4 microcon- troller clocked at 16 MHz was used as the main controller of the system.

The interface software application is written using Microsoft Visual C# with the use of Visual Studio Integrated Develop- ment Environment (IDE). The software application comprises of two windows. One is to display and control data acquisition and the other is to retrieve gathered data in graphical format. A base of an electronics balance and a bubble level was used for the experimental setup for calibration. Precision weights were used for the calibration process. Any additional weight

on the loading setup has been tare by using the software. The capabilities of high speed data logging was demon- strated with the use of free fall ping-pong ball under gravity. The primary objective, collecting data simultaneously in high speed is achieved with a maximum data rate of 980 SPS.

Software Interface and Features

The software interface is developed in order to facilitate the user with several options for logging data and viewing logged data. Visual studio C# IDE is used to develop the interface. There are two main basic interface designs for data logging and viewing.

The developed software is used to communicate with the microcontroller using serial communication, which transmits data captured by ADS1299 simultaneous sampling ADC unit.

Software is designed to communicate with the microcontroller at baud rate of 230400. Hence it is capable of getting a maximum sample rate of 1000 samples per second from all three channels.

A. Data Logging Interface

Data logging interface is given by Figure 1. The following features in Table 1 were enabled by using several productivity features available in Visual Studio C# IDE.

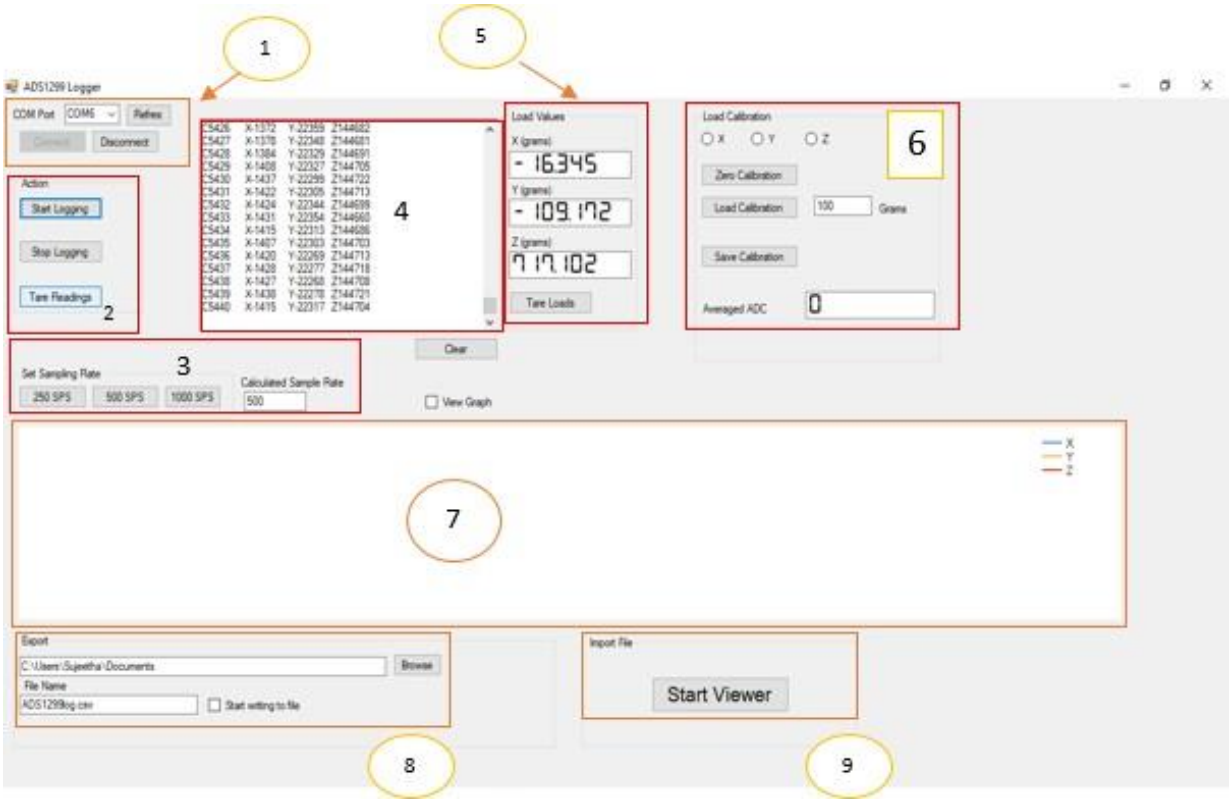


Fig. 1. Data logging software interface including the available features for the user..

The description of indicated numbers are included in Table 1

Table 1. Features/Elements Of The Software Interface

Feature/ Element	Description
1	Select the serial port and enable commutation
2	Start/stop reading data and tare input readings
3	Select sample rate and display actual sample rate
4	Display raw input data
5	Display the calibrated load values of x,y,z channels
6	Tools for calibrating the load values
7	View sampled x,y,z data graph
8	Exporting captured data
9	View saved data

Once the COM port which microcontroller is connected and selected from the software application, data acquisition is started. Start logging and stop logging buttons controls the data recording in the computer.

The microcontroller reads samples of x, y and z channels captured by the ADS1299 ADC and sends to the computer software with a sample count number. The software reads this string of data and separates the count x, y and z channels to separate variables. The sample count is used to calculate the actual sample rate and it is shown on the interface. The x, y, z variables are then used to calculate the load values using calibration curves of each channel. There is a separate section in the interface for calibration and using a known weight on each load cell axis, the calibration data can be acquired and stored in the software.

Calculated load values are shown on the interface and those can be tared at any point to adjust zero position. And these loads can be viewed on a graph for better understanding of motion. The angle of the force and the absolute value of the force on xy plane is also calculated and shown on the interface. Three buttons are given to change sample rates between 250, 500 and 1000 SPS. When these buttons are pressed, it will send commands to the microcontroller and it will change

the sampling rate of the ADS1299 chip.

All logged data is saved as a Comma Separated Value (CSV) file and a separate

viewer window is given to view and analyze these saved data.

The resultant force (F) was calculated using horizontal force

(x) and vertical force (y) and given by ,

$$F = \sqrt{X^2} + Y^2 \quad (1)$$

The angle of the resultant force (Θ) is also calculated using horizontal force (x) and vertical force (y) and given by

$$\Theta = \frac{tan^{-}1\ y/x}{\pi/180^{\circ}} \quad (2)$$

The angle of the resultant force is displayed in a direction chart.

Data Viewing Interface

The data viewing window of the software application is shown in Figure 2 and it facilitates user to view data in graphical format.

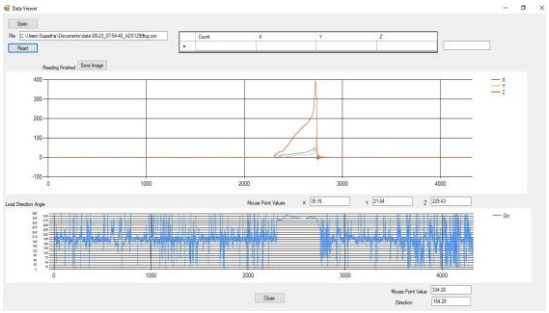


Fig. 2. Data viewing interface includes the loads in horizontal, vertical, lateral directions and load direction angel in y axis and the sample number in x axis

Calculating the instantaneous resultant force at exact point of jump is a semi-automated process. First the maximum force point is found using the saved data. It is done manually by displaying the data graphically. The point with the maximum lateral force is found first and the horizontal and vertical force reading is taken using the mouse point reading option. The data sample number at the same point is considered as the exact point of jump and the direction is taken from the load direction angle graph. The interactive graph can be zoomed in or out depending on the requirements. The graphs can also be saved as images for future references.

Results and Discussion

The system is calibrated for statistic weights using precision weights and calibration curves were observed. The Figure 2 shows the response of the developed system using the data

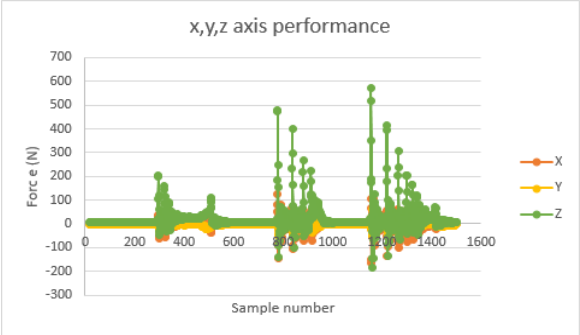


Fig. 3. Performance of x,y,z axis (free fall from height of 100mm), Force (N) in y axis and sample number in y axis

Viewing interface.

The angle of the resultant force is demonstrated by applying a force in different angles and as shown in Figure 4.The predicted angle and the angle calculated by the software was observed and Root Mean Square Error (RMSE) which is a measure of the accuracy of predictions made with a regression line was calculated for the data set as 0.52.However, the actual system is yet to be test with a frog.

Figure 3 shows the quick response observed with the data retrieved using the developed software.

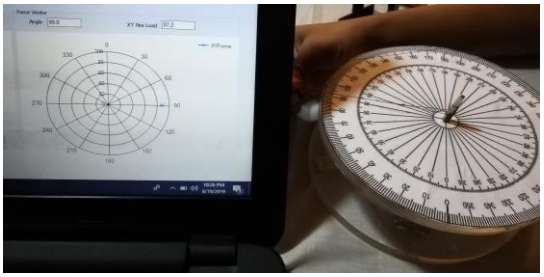
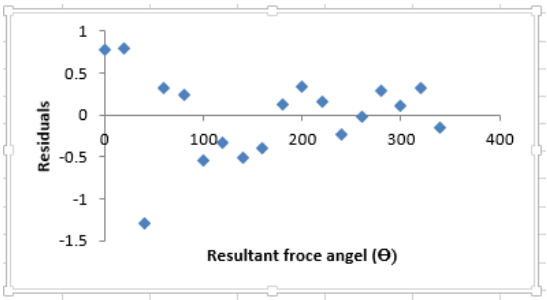


Fig. 4. Direction Chart, Response when applying a force from a known angel

Fig. 5. Resultant force angle, Residual Plot. By



using a data analysis software R Squared was calculated as 0.99 and RMSE was calculated as 0.52

Conclusion

The developed system is capable of recording dynamic ground force response of an object inserted on the platform. The primary objective, collecting data simultaneously in high speed is achieved with a maximum data rate of 980 SPS. The RMSE was found by considering calibration data with data obtained after calibration. The RMSE values for x axis was 1.05, y axis 0.84 and z axis was 1.10.

The developed system can be used to find the direction of the resultant force with RMSE of 0.52. But the system is not tested with real stripped mash frog at this stage. The data with this application will be collected and the possibility of determining the direction of jump will be considered as the next step of the project.

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Paper ID 146

Performance Comparison of Solid Tires and Non-Pneumatic Tires Using Finite Element Method: Application to Military Vehicles

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Abstract: Tire technologies are growing rapidly due to the high demand for applications in harsh environmental conditions. Solid and non-pneumatic (NP) tires are utilized in such conditions as transporting excessive loads, operating on rough surfaces, agriculture, construction industries and for military applications. These tires experience high stresses and excessive deformations due to sudden impacts and heavy loads. These factors are not easy to analyse experimentally due to complex experimental setups and high cost. Hence, the following study is focused on the characteristic comparisons of solid and NP tires by developing three dimensional (3D) Finite Element (FE) models under static and dynamic conditions. Initially, two FE tire models are developed for equal size of solid and NP tires. To obtain material behaviour of the tires, the suitable hyper-elastic material models are required and those are selected using a curve fitting approach. Experimental data are compared with numerical results to validate the developed models. The validated models show good agreement with experimental models. The static numerical results of the validated model show that high stresses are located in the base section of the solid tire. For NP tires, spokes and shear layer bear the stresses more than the other rubber sections. Moreover, curb impact is conducted for both tires by changing tire impact velocity. Results show that, the NP tire experiences higher impact stresses than the solid tire.

Keywords: Curb Impact Simulation, Hyper-Elastic Materials, Nonlinear Numerical Modelling, Non-Pneumatic Tire, Solid Tire

Introduction

There are three basic types of tires which are mainly used in the tire industry. These are pneumatic tires, solid tires and non-pneumatic tires. The pneumatic tires are the more popular tire type in the world. These tires are utilized in a wide variety of applications and mostly used in passenger vehicles. Solid tires are the more popular tire type in the construction fields, transportation sectors as well as nowadays, in military applications. These tires are flat free tires which have zero downtime and less maintenance requirements when compared to the pneumatic tires. In contrast, solid resilient tires are more popular in heavy duty vehicles due to its ability to operate in harsh environments while bearing excessive loads (Suripa, 2008; Phromjan, 2018). The non-pneumatic tires (NPT) and solid resilient tires (SRT) are the main airless tire types. Non-pneumatic tires have higher flexibility regardless of the running surface conditions, higher driver comfort level, do not burst and gives good stability to the vehicle (Baranowski 2015; Yazid 2015). Further, NP tires are utilized in military vehicles due to its ability to sustain and even operate under bullet hits and blasting conditions.

In the literature, limited studies have been conducted on solid tires. Suripa (2008), developed a simplified solid resilient tire FE model to investigate the distribution of tire strain energy density and deformation under different loads and different arrangements of the rubber layers on static conditions. Dechwayukul et al. (2010), proposed an experimental method to evaluate tire service life, life time of the tire at different loading conditions and speeds of selected industrial solid tires. Rukkur et al. (2013), conducted a laboratory experimental study to improve and reduce heat build-up at the tread layer of a solid industrial tire. Phromjan (2018), developed 3D FE tire model to analyse the tire behaviour on static conditions. Tire stress distributions and deformations were analysed using a detailed tire FE model. In addition, by conducting compression tests and curve fitting approach, the Ogden material model was selected as the best fitted constitutive model.

For non-pneumatic tires, an experimental and numerical investigation was conducted to reduce rolling resistance and energy dissipation of the NP tire by introducing porous composite shear band (Veeramurthy et al., 2013). In Baranowski (2015), a light military armoured vehicle blast loading was simulated for NP tires. To improve vehicle tire strength and resistance against the blast, the honeycomb type NP tires were introduced in their model. Yazid (2015), analysed the effect of NPT spokes arrangement on its performance. In 2017, Karthick et al., developed three different designs of NPT FE models by changing their thickness and shear modulus of the spokes and shear bands to analyse those modification's effects on the vertical stiffness, contact pressure and rolling resistance. Further in 2019, Zmuda et al., developed a validated numerical model of NP tires to observe the spokes and shear beam deformations under different loading conditions. In addition, the tire contact pressure was also investigated.

Only a static analysis was performed in the above articles. Further, according to the above studies it is highlighted that lack of dynamic analyses and characteristic comparisons of tires are investigated on both SR and NP tires. Hence, this study is conducted to compare the performance of SR and NP tires under static and dynamic conditions and evaluate their usability in military applications.

Methodology

This study is focused on the development of static and dynamic simulation models of tires with mathematical representations of SR and NP tires in three dimension (3D) to compare the performance of SR and NP tires. Figure 1 shows the methodology of the study. In the SR tire, base, cushion and tread are the main three rubber layers. Moreover, few bead bundles (reinforcements) are embedded into the base layer as the structural reinforcements. These three rubber layers are made by using three different rubber compounds and their properties are different to each other. The cross-section view of an SR tire is presented on Figure 2. In contrast, the NP tire has shear layer and flexible spokes which are made usually from polyurethane. In addition, it consists of a tread layer (Rubber), two reinforcement rings and steel rings. Figure 3 shows the corresponding view of a Tweel type NP tire.

The 3D hybrid hexahedron elements are used to model all the sections in SR and NP tires except two reinforcement rings in the NP tire. These reinforcements in NP tire are modelled using membrane elements. Further, suitable hyper-elastic material models are obtained by using relevant tensile data and curve fitting approach. The

static FE models of tires are simulated by using Abaqus/Std 6.14.

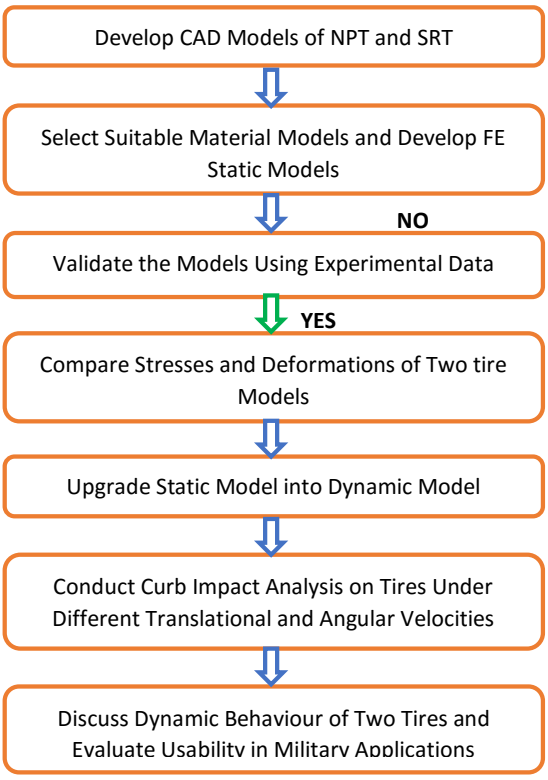


Figure 1. The flow diagram of the methodology

The properly validated detailed tire FE models are then used to compare stress and deformation behaviours of an actual SR and NP tires under different load conditions. Further, the developed static models are upgraded into dynamic models by introducing time dependent material properties, relevant boundary conditions and simplified tire models. The Abaqus/Explicit solver is utilized to conduct curb impact analysis on tires.

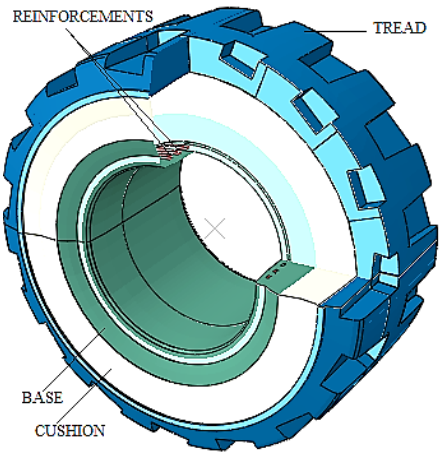


Figure 2. Cross section of a SR tire

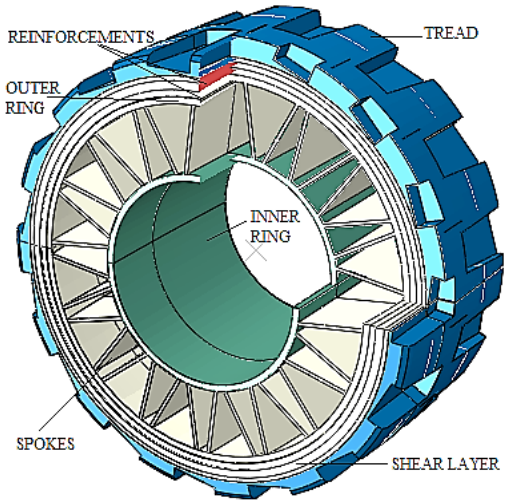


Figure 3. Cross section of a NP tire

Numerical Simulation of Tires

This section describes the development of static numerical models of SR and NP tires and their validations. In addition, the evolution of the curb impact dynamic models of the two tire types are presented.

A. Development of Static Numerical Models

In the static analysis, the detailed tire models are considered and tire deformations are gathered under different loading conditions to compare both SR and NP tire characteristics. In this study, a Tweel type NP tire and forklift SR tire of the same size are used for the analysis. The interactions and boundary conditions are applied on both tire models. Road is designed as rigid body and surface to surface interactions are applied both tire tread surfaces and road. A Control point is assigned on the centre of the tire rim which uses to apply loads. Furthermore, hexahedral elements are used to generate the FE mesh of both tires. The SR tire consists total elements 32204 and NP tire consists total elements 33132.

1) Best Fitted Hyper-Elastic Material Models and Static FE Models: To develop the FE models, the required best fitted constitutive models and material properties of the filled rubber, polyurethane (PU) and other reinforcements of the tires are gathered

through conducting relevant laboratory experiments. Here, the Yeoh hyper-elastic material model is selected using curve fitting approach to describe the mechanical behaviour of the filled rubber sections of both tires. Moreover, Mooney Rivlin material model is used to describe the behaviour of tire polyurethane sections. The corresponding constitutive models of Yeoh and Mooney Rivlin are presented in Eq. (1) and Eq. (2) respectively. Table 1 shows the coefficients of each material model.

$$W = \sum_{i=0}^{3} C_{10}(\bar{I}_1 - 3)^i \quad (1)$$

$$W = C_{10}(\bar{I}_1 - 3) + C_{01}(\bar{I}_2 - 3) \quad (2)$$

Where;

$\bar{I}_1, \bar{I}_2$ - The principal invariants
C_{ij} - Material constants

Table 1. Coefficients of material models

Rubber/PU Section	**Coefficients (MPa)**		
Base	C10	C20	C30
	4.993	-8.846	0.212
Cushion	C10	C20	C30
	0.671	-0.003	0.007
Tread	C10	C20	C30
	0.689	-0.021	0.008
Shear Layer and Spokes	C10	C01	
	-6.7	15.1	

C. Validation of Numerical Models

Figure 4 and Figure 5 show the comparisons of numerical and experimental data of tire vertical deformations under different load conditions. The deformation values of both numerical tire models show a good agreement with their physical experimental data.

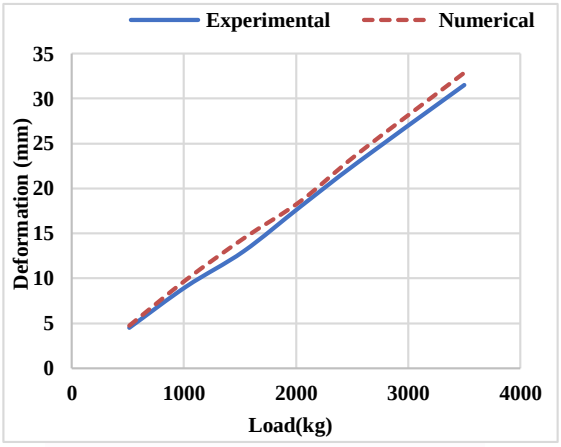


Figure 4. NP Tire vertical deformation: Experimental vs Numerical

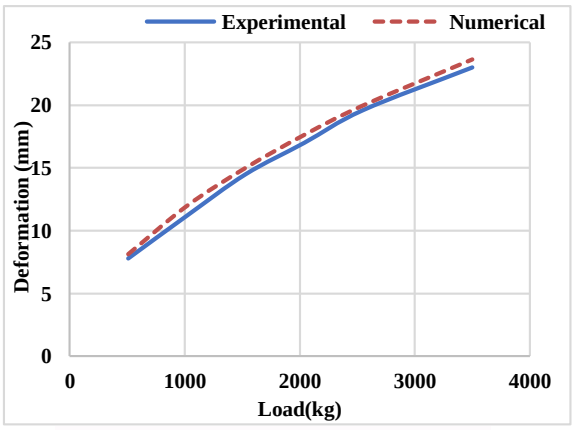


Figure 5. SR Tire vertical deformation: Experimental vs Numerical

C. Modelling and Analysis of Dynamic Numerical Models – Curb Impact

The dynamic models of the tires are created by introducing time dependent material properties of the rubber sections and polyurethane sections. Each material viscoelastic properties are defined using material relaxation data.

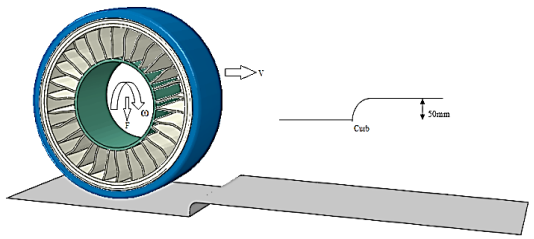


Figure 6. Visualization of tire rolling over curb

The tire tread patterns are ignored due to their insignificant effect on final results of

tire curb impact. Hence, simplified tire models are considered for developing dynamic models in order to reduce unnecessary simulation effort and time. To analyse curb impact, the road and curb are modelled as discrete rigid bodies shown in Figure 6. Further, three different translational velocities of 25kmh^{-1}, 15kmh^{-1} and 5kmh^{-1} are applied on the centre of the tire rim while keeping applied axial load constant (1530 kg) for three stages. The axial load is applied smoothly on the rim before starting translational and rotational motions of the tire. After that, the translational velocities and angular velocities (21.14rads^{-1}, 12.68 rads^{-1} and 4.23 rads^{-1}) are applied on the tire. The angular velocities are applied on the clockwise direction as shown in Figure 6.

Results and Discussion

A. *Stress Comparison of SRT and NPT Under Static Conditions*

The loads are applied on the tire models as 510kg, 1020kg, 1530kg, 2040kg, 2550kg, 3500kg respectively. The corresponding stress distributions of SR tire and NP tire are shown in Figure 7 and Figure 8 for rubber and polyurethane sections. Maximum von mises stress is observed on the base section of the SR tire. Moreover, for NP tire, the spokes and shear band are controlled the maximum stress.

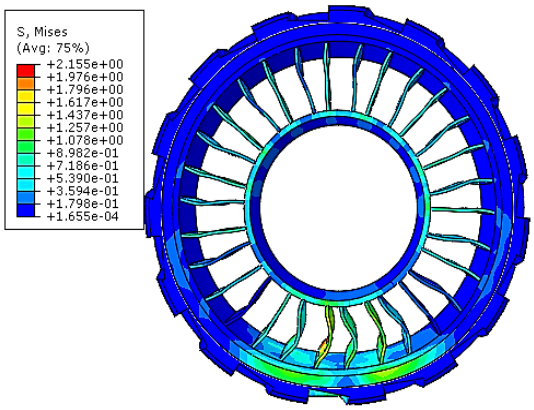


Figure 7. Max. von mises stress distribution of NPT rubber and PU components: Load-1530 kg

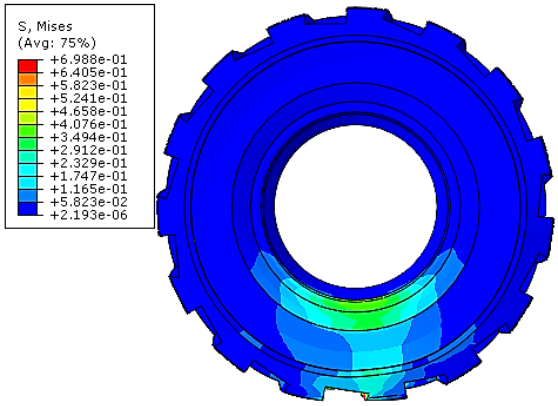


Figure 8. Max. von mises stress distribution of SRT rubber components: Load - 1530 kg

The stress variation and deformation comparisons of two tire models are presented in Figure 9 and Figure 10. For higher loads the stress of the NP tire is more dominant than the SR tire.

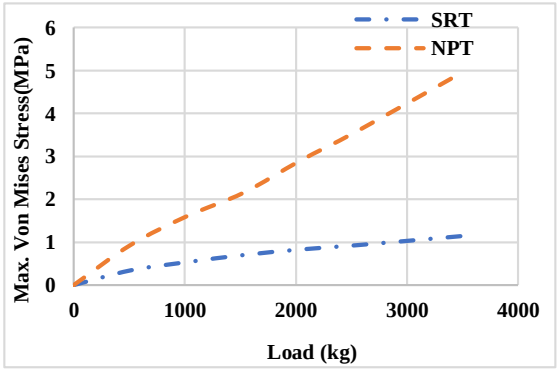


Figure 9. Max. von mises stress distribution comparison of SRT and NPT under different loads

Further, deformation (16.38mm) of NP tire (Figure 10: Point A) and the deformation of SR tire is the same at load 1750kg. Beyond load level 1750kg the deformation of NP tire higher than the deformation of SR tire. When load level is increased, the NP tire deformation level is increasing. That increases tire contact area and leads to higher wearing rate than the SR tire at the same load condition. Moreover, according to the industrial standards the maximum recommended load for NP tire varies between 1500kg to 2000kg such that, beyond these maximum limits NP tires perform poorly. Cron (2010) observed the intersection of two deformation curves at a

specific load level on non-pneumatic tires and pneumatic tires under static conditions. A similar intersection behaviour is observed for NP and SR tires in Figure 10. Furthermore, at point A, the secant stiffness value is the same for both the tires.

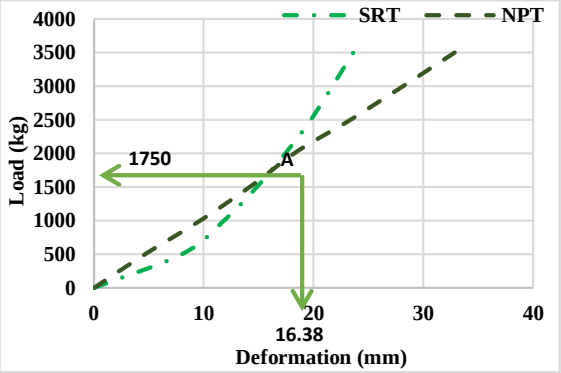
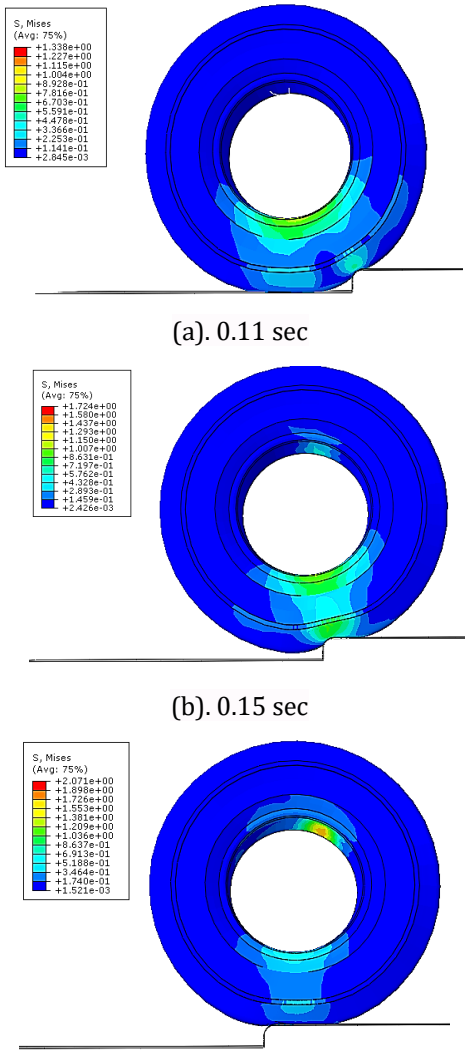


Figure 10. Deformation comparison of SRT and NPT under different loads

B. *Stress Comparison of SRT and NPT Under Curb Impact*

Figure 11 and Figure 12 present the tire positions and max. von mises stress distributions at different time stages of the two tire models. It clearly shows that the stresses in both of the tires vary with respect to time and speed. Further, at a speed of 5kmh^{-1}, the front side of the tires hit the curb at time 0.11 sec and maximum stress is obtained at time 0.15 sec. Further, the tires leave the curb at time 0.2 sec. These time frames are decreasing when the applied speeds are increased.

Moreover, when the SR tire is crossing the curb, the maximum stresses occurred at the base and tread layers of the tire rubber sections. Here, the cushion layer acts as a stress transferring medium in between the base and tread. In the NP tire, the maximum stresses are governed by shear layer and spokes.



(a). 0.11 sec

(b). 0.15 sec

(c). 0.2 sec

Figure 11. Max. von mises stress distribution at different time frames of rubber sections in SRT: (a) 0.11 sec; (b) 0.15 sec; and (c) 0.2 sec

Further, Figure 13 shows the comparison of stresses on both tires at different velocities. Here, the stress on NP tire is dominant than the stress on SR tire. This means that, at low load levels, the high stresses are efficiently captured and absorbed by rubber and polyurethane sections in NP tires than SR tires without transferring them to the vehicle body. The elastic and viscous parts in rubber and polyurethane sections, stores as well as returns the energy and absorbs energy respectively. Hence, NP tires produces a more comfortable ride, good stability and better mobility than SR tires.

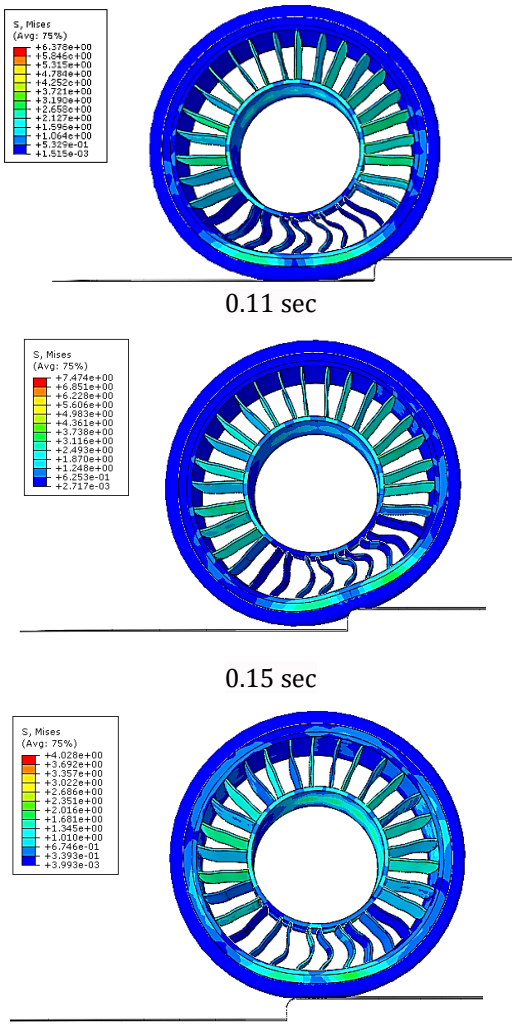


Figure 12. Max. von mises stress distribution at different time frames of rubber and polyurethane sections in NPT: (a) 0.11 sec; (b) 0.15 sec; and (c) 0.2 sec

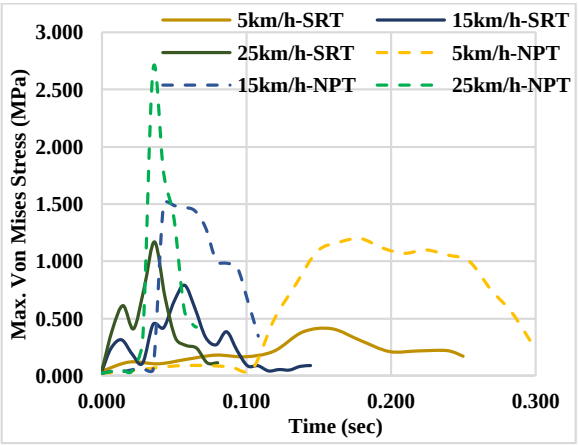


Figure 13. Max. von mises stress variation comparison of NPT and SRT under different velocities

Further, Figure 13 shows that the higher the velocity, lesser the impact time and higher the stresses generated on the tires.

Conclusion

Solid resilient tires (SRT) and non-pneumatic tires (NPT) are numerically modelled to analyse the comparisons of their characteristics under static and dynamic conditions. The FE models were developed to analyse and compare both SR and NP tires and their usability in military applications. The best fitted hyper-elastic material models were selected by curve fitting on test data. Yeoh and Mooney Rivlin hyper-elastic material models showed a good agreement with experimental stress-strain curves of rubber and PU sections respectively, and these material models were used to develop the numerical models. The numerical results were compared with experimental data to validate the models. The numerical results showed good accuracy in comparison with the experimental results.

Further, the validated numerical models were used to compare stresses and deformations of both SR tire and NP tire under different load levels in the static condition. The results emphasized that localized high stresses were mainly distributed in the base section than the other rubber sections of the SR tire. For the NP tire, high stresses were obtained on spokes and the shear layer than the rubber section. Moreover, NP tire model showed higher stress and deformation readings than SR tire under higher load levels. It was observed that, beyond certain loading limits the NP tire shows poor performances than the SR tire.

Additionally, an analysis of the tire impact on the curb was performed. To develop dynamic models the material time dependent data and relevant boundary conditions were introduced into the models. Here, stress variations of two tire models are investigated and compared under different impact velocities for a constant load level. NP tire presented

higher stress levels than the SR tire when the tires rolled at the same speed. This showed that the NP tires were more suitable for light military vehicles (military UTV and military ATV) because it has the ability to move at considerably high speeds on harsh surface conditions with more stability and mobility on the vehicle. In addition, the SR tires were more suitable for heavy military equipment and transporting goods.

The above analysis can be effectively performed using FE simulation methods and it can be used to investigate the capabilities of the different tire types and their characteristics. Moreover, this study can be further extended to improve tire performances on dynamic behaviour by changing tire design.

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Paper ID 156

Design of Pressure Sensing Circuit to Measure Pressure Distribution of Patient's Foot

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Abstract: Design of pressure sensing circuit and related parameters are discussed in this paper. A significant portion of the world's population is plagued by diabetes. It can deteriorate the organs of the body at a very high rate leading to fatal conditions, one of them being foot ulcers. The ulceration can lead to a choice between amputation of infected limb/s and loss of life. Deterioration of nerves cause the protective sensation to decrease with time. This causes high tensions in certain areas of the skin of feet due to poor judgement of weight distribution which in-turn causes the tissues to thin off and be torn layer by layer, resulting in ulcers. While prevention is better than cure, those that already suffer from and those that are recovering from such an ordeal would benefit very much from a handy device that can sense pressure distribution since it would help guide the patient to correct his or her gait movements accordingly. It would also be useful in selection of footwear since footwear can also cause change in gait. The idea is to build a prototype component that can measure and display the foot pressure of key points of the foot during gait at an affordable cost to a majority of the Sri Lankan population.

Keywords: Foot Pressure Sensor, Low cost, Foot ulcers

Introduction

Foot ulcers are a common but very dangerous medical condition that plagues diabetic patients around the globe. It can lead to amputation of limbs in order to save the patient's life and is caused by continuous exposure of the skin of the feet to high pressures during gait. The high pressures are caused due to pathomechanical changes in the foot in those suffering from diabetic neuropathy. These wounds tend to fester very fast since the healing properties of the body are retarded in a diabetic patient due to their weak immune system. A pressure sensing insole will help gather data about the pressure distribution of the foot of any human. This would help a doctor catch-on to any abnormalities in foot pressure distribution of the patient during gait and give advice on how to correct gait pattern to prevent from ulceration or to recover from such an ordeal. A person can use this to choose correct footwear that won't have an adverse effect on the person's gait.

An inexpensive pressure sensing insole could benefit the people of Sri Lanka since it would be affordable to many. While this can be used during recovery, its main purpose is to be used to prevent the occurrence of ulcers altogether by analyzing gait of diabetic patients at a continuous basis and correcting any abnormalities in gait as soon as they occur and by choosing footwear that won't affect the gait negatively when buying footwear.

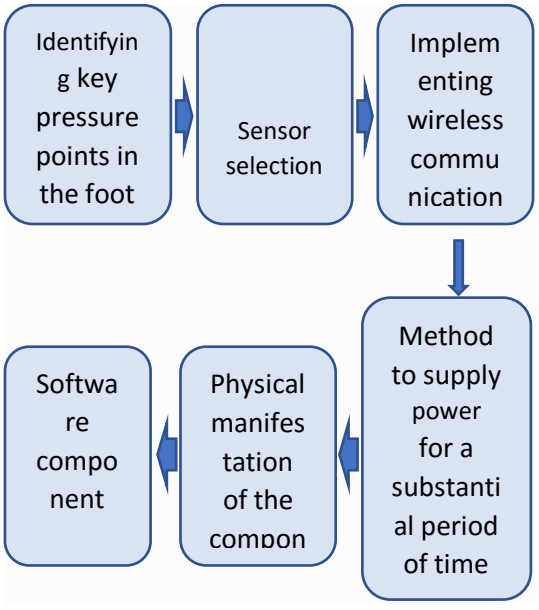
Proposed Method

The proposed method consists of only the pressure sensing feature, wireless communication feature and a method of supplying power to the component for a

substantial period of time. None of the additional features possessed by other market products would be included. And only a prototype will be made at this stage. The aim of the research was to design and fabricate a prototype for a low-cost pedobarographic tool for insole application for the purpose of measuring foot pressure during gait and displaying in real time.

The objectives of the research are design and fabricate a hardware component that has the capability to measure foot pressure during gait**,** implement a method to transmit sensor values to a device wirelessly, establish a method to power the component for a substantial period of time and display sensor data in real time. The outcome of the this would be Correction of gait movements during recovery, correction of gait movements to avoid consequences and an aide in choosing correct footwear.

Methodology



Design of Sensing Elements

At this stage only the sensor type and the placement were considered. The component used to sense force is called a load cell. This is commonly used in digital scales to measure weight. But its application is impractical in this scenario due to its bulk since it's necessary to keep the component as slim as much as possible.

The places that get the highest amount of pressure during pronation were considered. Regardless of whether the it is neutral pronation, over-pronation or under-pronation, the cycle starts with a heel strike, rolls along the length of the foot and ends at the metatarsus. Thus, following areas were determined to be critical areas after taking into account both the bone structure of the foot and pronation. They are the first metatarsal, the fifth metatarsal, the midfoot and the heel.

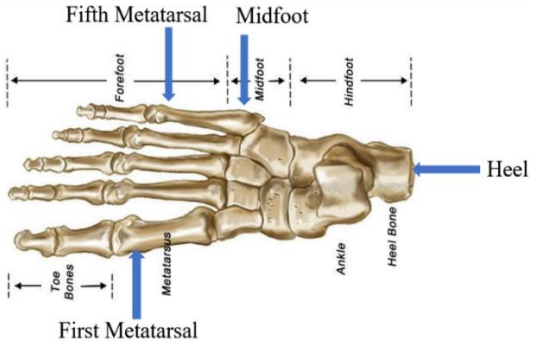


Figure 1 : The bone structure of the human foot

The placement of the sensors was changed to accommodate the adjustments mentioned. Four FSR-402 sensors were chosen at the beginning. FSR sensors do not give a linear output. The datasheet of both sensors shows a force vs. output-voltage graph. It's in the shape of a logarithmic graph. The graphs are similar for both sensors. The micro-controller receives and outputs an analog value. But while the output voltage is between 0 and 3 V, the analog values range from 0 to 1023. During testing, even when a weight is placed on the sensor, it gave 0 as an output up to a certain weight/force value. This phenomenon can be clearly seen in the force vs output curve given in the datasheet. Therefore, calibration is necessary in order to get rid of this problem.

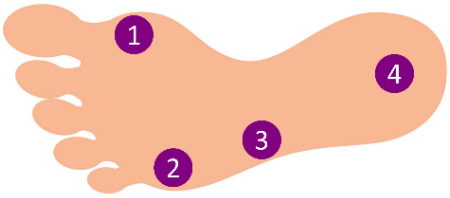


Figure 2 : The sensor placement

For charging the battery, the charging module TP4056 is used. There's limited information regarding the charger regardless of its popularity. It is a constant-current/constant-voltage linear charger for single cell lithium-ion batteries. Its architecture makes it a suitable candidate for portable applications. The charge voltage is fixed at 4.2V which also can be set externally with the use of a single resister. Once the charge current drops to 1/10th of the predetermined value and the final float voltage is reached, the component automatically terminates the charge cycle. Aside from that, current monitor, under-voltage lockout, automatic recharge and two indicators to represent charge termination and charging status are the other features of the component.

It is necessary to have a method of transmitting the sensor values from the component to the PC for further processing. As mentioned in the literature review, most products use expensive Wi-Fi modules to achieve this communication. But there are other methods that can be used to facilitate such communications; using a Wi-Fi module, a Bluetooth module or an ESP-8266 microcontroller.

Wi-Fi has the advantage of not having the PC close-by for communication since it can transmit data via the internet to anywhere in the world. But the cheaper Wi-Fi modules available in the market are ridiculously bulky. So, the option is dropped immediately. On the other hand, the Bluetooth module is very small in size, light in weight and very cheap. It is also more than enough for the action of transmitting for sensor values to the PC, the only disadvantage being that the device should be within the range of the component for it to work. But the drawback is acceptable since it is a prototype. The ESP-8266 micro-controller is another handy option available for this kind of work. It was indeed a very attractive option since it has an inbuilt Wi-Fi module, it's cheap, light in weight and having an inbuilt Wi-Fi module reduces the waste of space that occurs when using a separate device for communication. But the micro-controller does not possess the necessary number of analog pins to connect all the sensors.

Sensor Placement and Wiring

The sensors were attached to the top surface of the slipper according to measurements of my foot using double sided tape as shown in Figure 3-16. Then copper wires were soldered to each sensor terminal. All the negative terminals were connected together using a single wire. Then the wires were passed through the rubber layer to appear at the bottom-side of the slipper and the top-side of the cut square as shown in Figure 3-17.

Figure 3: The placement of the sensors on the top surface of the slipper

Figure 4: The cut on the underside of the slipper to made to accommodate the box and the wires drawn out from the sensors

Accommodation should be made for the necessary support components too. Initially, the decision was to cut out a small cuboidal material from the bottom of the slipper and place the components in it. While the components themselves are slim and doesn't occupy much space height-wise, the wiring takes up space. Therefore, a bigger space is needed which means more material had to be cut-out from the slipper thus threatening to weaken the stability of the slipper. So, a small box was designed and 3-D printed to place the components and house the wiring in. Then the box was placed in the cut-out.

Microcontroller Programming and Device Calibration

The program uploaded to the microcontroller was written in Arduino IDE. In-built commands and functions are utilized here to configure the sensor pins, read the data received from the sensors and send the data to the Bluetooth device. The Baud rate is set to 9600. The baud rate is the number of symbol changes, waveform changes, or signaling events, across the transmission medium per unit time and should be mentioned when initiating a serial communication of any type for synchronization purposes.

Calibration is necessary to confirm the authenticity of the data obtained by the component. In this case, the sensors, individually, gave an increasing relationship with weight. But tests needed to be done once they are connected to the circuit of the component to see if the values given by the component increases with the weight. So, it was tested by keeping known weights that were increased by a kilogram after 15 seconds.

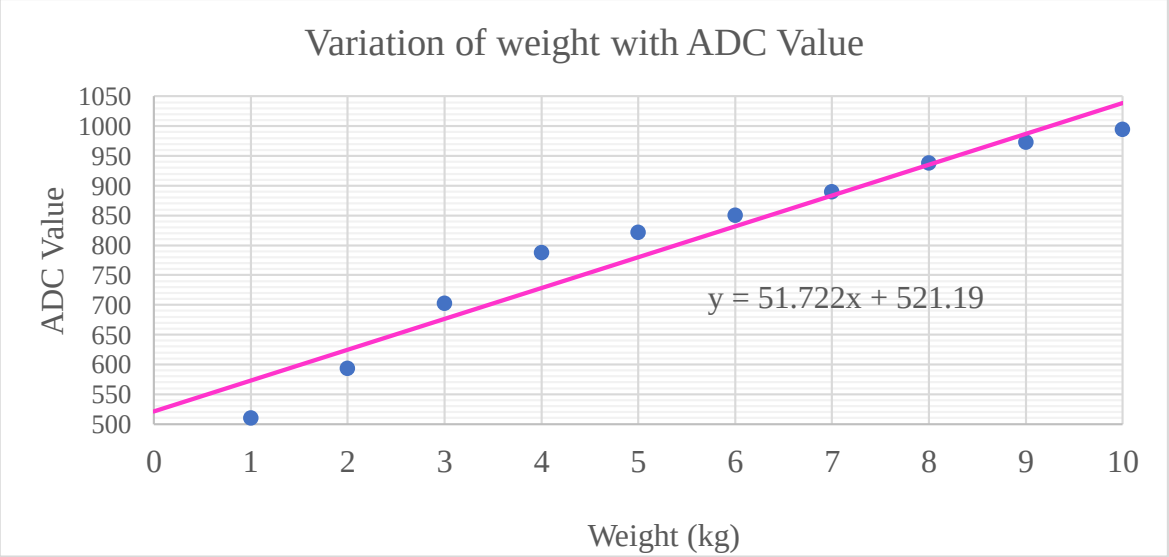


Figure 5: variation of sensor value with ADC value

The data collection and calibration was done in order to get final design. the collected data is the sensor values when the sensors are stimulated. The obtained value is then converted to a decimal value between 0 and 1023 by the microcontroller and sent to the PC. When the data comes through a serial communication to the computer, it comes through a port, a serial port, to be specific. It's called a communication port or COM port for short. A COM port could be either physical or virtual. The port of any device connected to the PC could be viewed using the device manager feature of the PC. A Bluetooth communication forms a virtual port also visible in the device manager.

Results and Discussion

This analysis was centered mostly around the heel sensor. It was impossible to pinpoint on the smaller FSR-402. Its smaller size means it changes values erratically during testing at the slightest provocation. On the other hand, the heel sensor gave off steady readings. The tests were done for 15 seconds each for standing, walking in the clockwise direction and walking in the anticlockwise direction.

The components need to ensure the physical demands of such a component are very expensive. It was decided to settle to designing a working prototype that can be used for experimentation in order to test the feasibility of the component. Therefore, the aim of keeping to a low cost was realized. The cost of the prototype is shown in the table below. It is an acceptable amount that can be afforded by majority of the population.

Conclusion

The feasibility of the component was confirmed, the aim and the objectives are fulfilled, thus, overall, the endeavor turns out to be successful. Devices can be recommended to use to prevent this from happening early on by keeping an eye on the gait pattern of a diabetic patient and correcting it when it strays. It can be used as a preventive device by being used during footwear selection. It can be used as a rehabilitation aid for a patient recovering from the condition. The quality of health of the country can be improved by using this kind of advanced bio-medical devices. It'll also have a positive effect on the economy of the country since healthy citizens means less drain on the country's resources due to health services

Paper ID 537

Development of a Semi-Automated Device to Lift and Transfer Bedridden Patients

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Abstract: Transferring bedridden patients from one flat surface to another, i.e. from a bed to a stretcher or laboratory/theater bed, is one of crucial activities carried out in healthcare facilities. It is a physically challenging task with many concerns on patient's safety and comfortability. None of the existing methods used for that task provides effective solution. Hence, this study aims at providing a mechanism to transfer bedridden patients with greater safety and comfort while reducing the human involvement.

The study was carried out in four phases. Initially, data collection was carried out to identify variety of methods, devices used for patient transferring both locally and globally. Further, a survey was done to identify main factors affecting when performing a transfer by interviewing all stakeholders of the activity including doctors, nurses, attendants, lab technicians. Secondly, design phase was completed. Thirdly, designed device was fabricated and finally, it was tested to refine and improve further. Developed design is a semi-automated device which needs only one operator to operate. When using it, patient's orientation is not required to change, and no any human effort needed. All the lifting and transferring movements are matched to standards given by WHO. Machine was tested using real size dummy as the patient and feedback was obtained from variety of medical staff involving with patient transferring. Qualitative data collection was done on performance. As per the feedback on testing, device is capable of providing a safe, comfortable and less physically demanding mechanism to transfer bedridden patients.

Keywords: Patient transferring, Automation, Elector-mechanical device, Safety

Introduction

Healthcare industry has evolved greatly due to the technology development. It has improved the efficiency, accuracy, safety, comfortability and effectiveness of large spectrum of activities in the sector from diagnosing illnesses to performing brain surgeries. One such area is handling patients in healthcare institutions.

A person, who is bedridden with physical disabilities, is vulnerable to various health complications like fractures, bedsores and depression due to lack of motion for long periods. Hence, they are both physically and mentally strained. On top of that, a bedridden patient needs to move from one place to another for various requirements such as medical testing/operations, personal hygiene etc. Lifting and transferring of patients in that condition is quite difficult, challenging and risky task.

There are number of factors to be considered when handling a bedridden patient, namely safety, comfortability of patients, physical effort required from handler. Safety is the utmost important factor which always considered as the priority. Due to safety concerns, handling of bedridden patients is performed variably depending on the condition of the patient.

However, when safety comes first, it comes with a trade off with comfortability. Even though handling crew perform the tasks with good care, patience and understanding, maintaining comfort when transferring is a greater challenge in the present context. In order to improve both safety and comfortability, one of the practices is having 4-6 number of staff members for the task. Yet, that alone can reduce comfortability and safety when proper coordination is absent. Thus, to reduce the human effort needed, different devices have been employed.

To date, there are various types of bedridden patient handling methods have been developed. Slider sheets, transfer belts, slider/transfer board and rolling slider/transfer board are few of such. However, they have number of drawbacks. Due to unavailability of an effective transferring method, both medical crew and patients face numerous difficulties. Thus, this study is focused on filling that void by developing an effective mechanism to transfer bedridden patients safely and comfortably with minimal human effort.

Literature Review

A. Factors Affecting a Safe and Comfortable Patient Transfers

Due to the growth in old age population, patients who confined to a bed because of old age and various illnesses have risen in recent past (R. Sheng et al., 2017). In addition, requirement for transferring patients from one support to another, one place to another has also increased with numerous medical requirements. Hence, patient handling is a crucial task that needs more attention for improvement.

Patient transferring has been categorized based on level of support needed from an outsider. There are three types,

- Independent transfers: In this, no any support from outside is needed
- Assisted transfers: Patient actively participates to the transfer, yet caregiver's assistance needed.
- Dependent transfers: Caregiver performs the whole transferring act while getting no or minimal involvement of the patient.

For assisted or dependent transfers, level of involvement of caregiver can be stand-by assist or minimal, moderate and maximum assistance. Bedridden patients undergo either assisted or dependent transfers.

In order to have a safe patient transfer, risk factors associated with patient, setup and instruments have to be identified and properly managed. In relation to the condition of the patient, his ability and level of communication, cognition (memory, judgement etc.), medical status (diagnosis, pain, supported devices, medication etc.), physical status (weight, height, balance, range of motion) and emotional status (resistive, aggressive, supportive, unpredictable etc.) are critical factors to be considered. Moreover, layout of the premises, space availability, lighting condition, obstacles and floor are few of the factors listed under setup. Moreover, risk factors associated with instruments include, improper use of instruments or use of faulty ones, wrong calibrations, inadequate training for use of equipment, attached life supports. Thus, formulating a safe and comfortable handling methods for bedridden patients' needs consideration of wide range of factors.

B. Transfer Assistive Devices

In the literature, wide range of patient transfer assistive devices and methods have been proposed. These includes sliding sheets, transfer belts, slide/transfer boards and rolling slide/transfer boards. However, in modern times, technology has been used to develop devices which need less human effort. These devices can be mainly

categorized in to two based on the method they use. Lift-sliding transferring method and horizontal moving method.

Under the first category, lift-sliding transferring, number of different mechanisms have been developed Xu K., et al., 2016, Jiang JG et al., 2016). Xu K., et al., (2016) has proposed a portable patient lifting mechanism as shown in Figure 1. This includes worm gear arrangement to lift patients while grabbing is done using opening and closing hand grasping mechanism. It has a simple structure and occupy less space but have limitations of adjustment requirement of lifting height and grasping has made it less usable.

Conversely, a patient transferring robot has been developed by Jiang JG, et al. (2015). This mechanism driven by two screws to lift and transfer. Main advantage of this is when transferring, patient's original posture can be maintained. However, due to cantilevered nature, device has to be larger.

In the second category, horizontal movement method, Figure 2 shows one of the methods proposed. It mainly uses U-rail to horizonal transfer of patients from hospital bed to transferring bed and from that to operating bed. However, this demand few retrofits to hospital bed and other connecting supports. Even though it gives more stable transferring it needs retrofitting when use for different setup.

R. Sheng, et al. (2017) has provided number of recently developed patient transferring mechanism and reviewed their advantages and disadvantages.

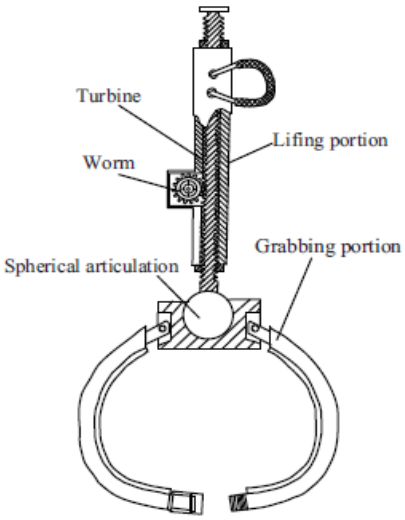

Figure 3. A portable patient transferring apparatus

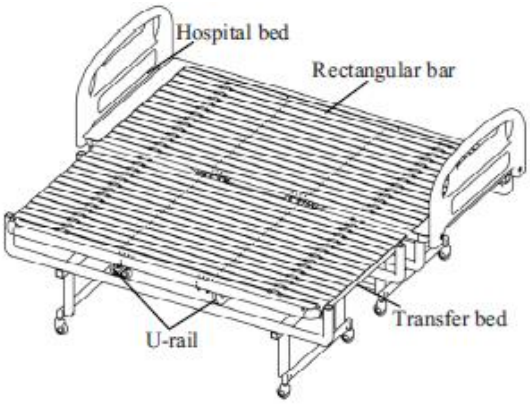

Figure 2. A translational patient transferring device

Methodology

Figure 3 shows the methodology followed in this study. Firstly, a survey was conducted to collect data on current practice of transferring bedridden patients. It was carried out in University Hospital KDU. Following data were collected through structured questionnaires and interviews conducted covering all stake holders of the activity.

- Current methods used
- Arrangement of wards and their layouts
- Experiences of medical crew on handling bedridden patients and challenges faced
- Different transferring requirements

Initially, required features of the patient handling device were gathered. Smooth operation, high accuracy, ease of controlling, withstanding high loads, less noise and low cost are the main factors highlighted.

In terms of methods used, it was observed that only transfer boards are used in local hospitals. This is a manual process which needs minimum of 3 caregivers' involvement. Additionally, ward beds, theater beds and trolleys were observed for their operations and powered alternatives. One of main findings was electrically driven machines provide smooth movements which is ideal for medical conditions.

Another observation was the value of the HMI (human machine interface) in machines. Both ICU bed and the theater beds use HMI to give instructions to the control unit of the machine. It provides user-friendly mechanism for the operator to control the machine easily. HMI interlinks the operator and the device. Actual components and the functions can be created inside the HMI. Because of that it is very easy to use without having much more knowledge on technical background of the machine.

After collecting all the required data, design, fabrication and testing phases were completed which are discussed in detail in the following sub sections.

A. Design of the Machine

The 3D model of the final design of the machine is given in Figure 4. The maximum operational area and the general dimensions are determined based on standard ward layouts of hospitals. The maximum load that the machine can handled is set to 100 kg. The Device consists of six assemblies denominated as machine base, dynamic structure, machine bed, lifting and transferring units, lateral transferring and controlling unit.

Initially air mattress is placed between the patient and the surface of the bed. Air mattress is inflated by the air blown into it. After placing the device, height can be adjusted to the required level Cotton strips are connected to the mattress manually. AC electric motor provides rotational motion to the transferring shaft. When strips wind, patient is transferred to the machine bed with air mattress. Lateral transfer plate is able to move towards the bed and safely transfer the patient to the bed.

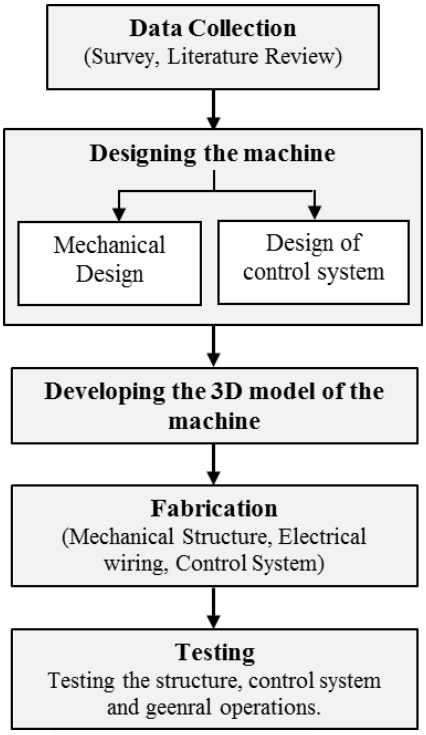

Figure 3. Methodology

Figure 4. 3D Model of the machine

Power requirements of all motors which were used for lifting, lowering and lateral transferring are calculated using equation (1).

$$P = \tau\omega \quad (1)$$

To adjust the height of the machine bed special mechanism is used. Similar mechanism to the cam mechanism is used for the dynamic structure. Purpose of selecting this mechanism is to minimize the axial thrust on lead screw. Two triangles were designed to achieve this cam motion. One metallic triangle is able to rotate around its horizontal axis. Another triangle is mounted to the eccentric position, because of that when lower triangle rotates around its horizontal axis upper triangle is able to achieve linear upward and downward motion.

AC geared motor with lead screw was mounted to the cross-link shaft. When the motor rotates leadscrew achieve rotational motion. Nut is mounted to a hollow shaft which is mounted to the cross link of the dynamic structure. Screw is mounted through the nut. When the screw rotates nut achieve linear motion. In the clockwise rotation of the motor, nut gives an axial thrust to the cross link through hollow shaft. In counterclockwise rotation of the motor nut gives pull to the cross link. From this push and pull machine bed achieves its upward and downward motion. Because of this motion height adjusting is possible. Device is designed for maximum load of 1000 N on the machine bed. Equivalent load with other components is 1250 N.

For lifting and loweing the mechanism, double start screw has been used. Diameter and the pitch of the screw respectively 20 mm and 2 mm. Torque required to raise the load is given by the equation,

$$T = w\left(\frac{Tan\alpha + Tan\varphi}{1 - Tan\alpha.Tan\varphi}\right)\frac{d}{2} \quad (2)$$

$$Tan\varphi = \frac{\mu}{Cos\beta} \quad (3)$$

$$Tan\alpha = \frac{Lead}{\pi d} \quad (4)$$

(w: load to be lifted, T: required torque of the motor, α: helix angle, μ: coefficient of friction between the screw and nut, d: mean diameter of the screw)

$$Tan\alpha = \frac{2 \times 4}{\pi \times 20} = 0.127$$

$$Tan\varphi = \frac{0.15}{Cos15°} = 0.155$$

$$T = 1250\left(\frac{0.127 + 0.155}{1 - 0.127 \times 0.155}\right) \times \frac{20}{2} = 35.95\ Nm$$

Torque required to lower the load is given by,

$$T = wTan(\varphi - \alpha)\frac{d}{2} \quad (5)$$

Here, φ > α therefore self-locking of the screw secured.

Lateral transferring is done by, winding strips around upper cross bar. Friction force between the transfer mattress and the bed creates a resistive torque to the applied torque from the motor. Friction force between the transfer mattress and the bed can be written as in the form:

$$F = \mu R \quad (6)$$

(F: friction force between the transfer mattress and the bed, μ: coefficient of friction between fabric surfaces, R: Reaction force to the applied load on mattress)

Strips attached to the mattress and the winding shaft is 30º inclined to the horizontal plane.

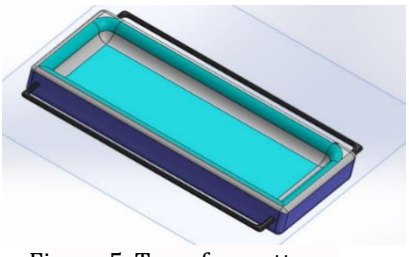

Figure 5. Transfer mattress

Required torque for lateral transferring can be written as in the form:

$$\boldsymbol{T} = (TCos30° + TSin30°)d \quad (7)$$

(**T**: required torque of the motor, T: Tension of the strips, d: diameter of the shaft)

$$\boldsymbol{T} = (0.56 \times 1000 + 1000)0.02 = 31.2\ Nm$$

Transfer mattress is an air mattress which is inflated with compressed air. In the proposed design, for the transfer mechanism inflated air mattress is used to avoid the direct contact with the patient and the rough surfaces of the machine and medical bed and to provide more comfortable transfer to the patient.

Device consist of two AC motors and one DC motor. Main functions of the machine are,

1. Elevating the bed
2. Lowering the bed
3. Linear forward motion of the bed
4. Linear backward of the bed
5. Clockwise rotation of the conveyer (Roll in)
6. Anti-Clockwise rotation of the conveyer (Roll out)

Controlling of the machine is done by Arduino Mega 2560, relay modules and L298 DC motor drive. DC 10A power supply was used to power electronic components and DC motor.

B. Stress Analysis

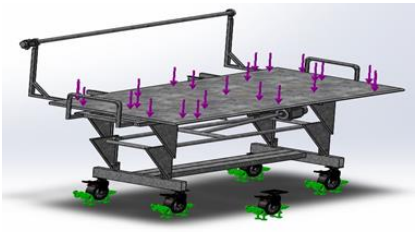

Figure 6. Application of 1000 N on machine bed

Figure 6 shows stress and material distribution of the device for applied 1000 N distributed load on the machine bed. Deflection of the cantilever lateral transfer plate is 0.3 mm at maximum distance. Stress in dynamic structure and most critical parts were in safe region. Stress analysis proved that the structure of the device withstand maximum applied force condition and device is safe for all applied force conditions below 1000 N.

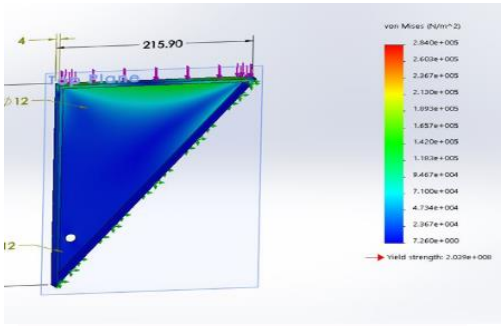

Figure 7. Stress distribution in dynamic structure

C. Fabrication

optimal dimensions and materials for the fabrication is obtained from aforementioned design calculations. Most of the subassemblies were made of galvanized steel box bars and sheet metal. Entire components of the machine are mounted on the base. Caster wheels are mounted to the machine base which making the device portable. Base of the machine made of 2mm thickness galvanized steel box bars. Thickness of the box bars and the material were selected to the withstand the force and stress acting on the machine.

Caster wheels are able to achieve rotational motion around its vertical axis and the circular motion around it's horizontal axis. Wheels can be locked in desired position which holds the whole machine at a steady position. To join the ribs and webs of the chassis welded joints were used as fabrication method. 3mm thickness sheet metal was selected for fabrication of this triangle to withstand dynamic and fatigue stresses. Eight triangle sets were interlinked using ¾ mm galvanized hollow steel pipes. Because of these interlinks all four triangle sets work together.

On top of the machine bed lateral transfer plate is mounted. Structure of this plate is made of one-inch square box bars. This steel structure was covered galvanized quarter millimeter thickness sheet metal

plate. This provide a smooth surface to slide the transfer bed on the lateral transfer sheet. In front of this lateralled transfer sheet metal nose was mounted using reverted joints. Riveted joints were used to mount sheet metal plate to the box bar structures. This inclined plane provides a supportive surface to take the transfer mattress from the medical bed to the machine bed.

Figure 8. Lateral transferring unit with complete machine structure

A lead screw is mounted to the lateralled transfer sheet. Ball screw was used for this purpose. To the end of the ball screw DC motor is mounted using gear wheels. Gear wheels were fabricated using bronze alloy. Gear wheels were tempered to increase its properties. When the DC motor rotates it provides a rotational motion to the ball screw. Ball nut is mounted to the lateral transfer sheet. Because of that its rotational motion is restricted. Therefore, when the ball screw rotates ball nut achieve linear motion because of this linear motion lateral transfer sheet is able to achieve forward and backward motion in horizontal plane.

To guide the lateral transfer sheet two metallic rails were used. For this rails 3mm thickness iron plates were used. Plates were cut and bend using the hydraulic metal cutter and bender machine. Linear guides were mounted to the lateral transfer sheet. For each linear guide six bearings were used. To avoid the movement and ease the motion two nylon wheels were used.

Transfer the patient from the medical bet to the machine bed, special kind of mechanism is used in this machine. A shaft is mounted to the machine structure with the support of the bearings. These bearings provide the mount and enables the rotation of the shaft. One end of the shaft is mounted to an AC motor. Stripes were used to link this rotating shaft and the transfer mattress. When the shaft rotates strips wind around this shaft. Because of that length of the stripes gradually decreased. Therefore, tension in strips will be increased. Because of this tension created by the strips acting on the transfer mattress, it tends to move toward the machine.

To enhance the appearance of the patient lifting and transferring machine and to prevent corrosion of the metallic parts painting was done. When the paint is applied, contact of the metallic parts with the oxygen and moisture are avoided. In order to avoid corrosion, welded joints were grinned well to clean and remove the rust. Then metal filler was applied. Surfaces were smoothened using sandpapers. When required smooth surfaces are obtained metal primer was applied. Then lacquer was applied according to the color of various components. Blue color was applied to the machine bed and white color was applied to other components because it provides more comfortable vision to eyes.

Figure 9. Semi automated patient transfering device

D. Testing

Device was tested with 1000 N load as the maximum load applied. Obtained test results were considered in optimization of control system. Machine is operated by the AC 220 V, 50 Hz power supply. 10 A DC power supply converts AC into DC and power the electronic control unit. Program code, delay time, relay operation and HMI instructions were ensured in testing of the device. Visual inspection was carried to analyze the physical condition of components.

To enhance the effectiveness of the evaluation process, feedback of the different categories in health care industry towards the patient lifting and transferring semi-automated device was evaluated by a points system. Five major outcomes of the device were listed and given to the relevant category in health care industry for their feedback. They are allowed to give a value between one to ten (1-10) for each outcome according to their judgement. Four members were taken from each category for the evaluation process.

Table 8: Points table

Category	Identification	Patient Safety	Patient Comfortability	Ease of use	Flexibility	Reducing Human Effort
Doctor	D_1	9	9	9	7	9
	D_2	8	8	9	8	9
	D_3	8	8	9	7	9
	D_4	8	8	8	7	9
Nurse	N_1	7	7	7	7	9
	N_2	8	8	8	7	8
	N_3	7	8	8	7	8
	N_4	8	7	8	7	8
Care Givers	C_1	7	7	7	8	8
	C_2	7	8	7	7	7
	C_3	8	7	7	7	7
	C_4	7	7	7	6	8
Technician	T_1	8	8	8	7	8
	T_2	8	7	8	6	9
	T_3	7	8	8	8	9
	T_4	7	7	8	7	8
Sum of Points	16	122	122	126	113	133
Total Points		160	160	160	160	160
Percentage (%)		76.25	76.25	78.75	70.625	83.125

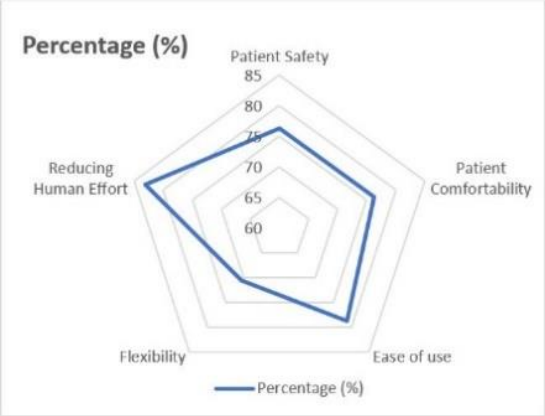

Figure 10. Summary of test reuslts

Discussion and Conclusions

Lifting and transferring a bed ridden patient is a quite difficult and risky task. To avoid the difficulties of this process various kinds of transferring methods and equipment are introduced. Risk and difficulties produced mainly due to the drawbacks of conventional transferring methods number of human involvements for the process is very high. Person who involves with this process should have a specific knowledge and proper training before to do this successfully. This research aimed to find a solution for a safer, less human involvement and comfortable patient transferring process. Thus, a semi-automated patient lifting and transferring machine for bed-ridden patients was designed and developed in this study. This device is an electro-mechanical device which can be operated by one person. The device was designed by gathering main requirements and concerns of all stakeholders of the process.

This machine has increased reliability and accuracy in operations when compared to existing devices. Furthermore, compact design, compatibility and user-friendlyness are also highlights of the proposed design. A qualitative testing was done using various stakeholders of the process to verify the operational performance of the device.

Acknowledgment

Authors would like to thank the University Hospictal KDU for providing opportunity for data collection and testing of the device.

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Paper ID 05

Real-Time Vision-Based & Optimized Pedestrian Crossing Control System

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Abstract: As per the National Council for Road Safety, more than 900 fatalities have been reported due to vehicle collisions on or near pedestrian crossings during the past 10 years within Sri Lanka. However, only minimal research has been carried out so far to improve the safety conditions of pedestrians. This research focuses on developing a system utilizing image processing to obtain the real-time data of a group of pedestrians at crosswalks and determining of an optimal time frame for a certain group of pedestrians to cross the road at a given time period. This study concludes on the necessary requirements to optimize the timing of the existing push-button based signaling system. A mobile based app is also developed to assist drivers to be incorporated with the proposed signaling system to enhance the end-effect. Extensive trials prove that the proposed system would ensure pedestrian safety and minimize or even prevent reckless road collisions within crosswalks.

Keywords: Pedestrian Safety, Image Processing, Road Traffic, Pedestrian group density, Vehicle queue density.

Introduction

Different people may follow diversified modes for transportation, however at one time or another everyone may act as a pedestrian. A pedestrian crossing or a crosswalk is a pedestrian's path of travel across the motorist's path of travel, where the pedestrian should ideally be given the priority. At pedestrian crosswalks, pedestrians have the right of access as in some countries [6] pedestrians are given right of way as soon as they step on the crossing. However, pedestrians will have to start crossing the road to get the right to access [1] in some regions.

Pedestrian crosswalks are either established at a junction, called intersection crossings, or just on the road where there are necessarily no intersections but are needed due to the high vehicle density, speed, and width of the road, known as midblock crossings. Pedestrian crossings can be classified into two categories as signalized crossings and un-signalized crossings. Signalized crossings are with control devices that clearly separate pedestrians from vehicles in the area of the crossing. Un-signalized crossings are the type that generally offer no assistance to pedestrians.

Pedestrians are the mostly vulnerable and slowest type of traffic or movement on the road. Marked crossings can provide a sense of false security which makes pedestrians enter without assessing the traffic situation. Pedestrians also tend to presume vehicles would stop at any instance which is obviously may not be the case. The fatalities that occurred on or near pedestrian crossings in Sri Lanka during last 10 years are presented in the table 1 below:

Table 1. Pedestrian Fatalities at Pedestrian Crossings in Sri Lanka over the last decade according to Colombo Municipal Council (CMC)

Year	Number of Fatalities at pedestrian crossings
2008	71
2009	94
2010	120
2011	110
2012	110
2013	112
2014	119
2015	122
2016	130
2017	120
2018	117

It can be observed that pedestrian collisions on crosswalks are in fact at a very serious state and a delicate issue that needs to be urgently deemed.

The main risks to pedestrians are well recognized, and they include issues related to a broad range of factors such as driver behavior, specifically concerning speeding as well as drinking and driving; lack of infrastructure in terms of dedicated facilities for pedestrians such as sidewalks, crossings, and raised medians; and vehicle design in terms of solid vehicle fronts that are not forgiving to pedestrians should they be struck.

Whether a certain crosswalk is signalized or not doesn't mean it is safe as most drivers don't necessarily acknowledge the presence of a crosswalk on the road and most pedestrians don't acknowledge the vehicle density and their speeds when crossing the road in Sri Lanka. Pedestrian crosswalks are an important element in road networks and there are hundreds of different crosswalks all over Sri Lanka. This research was based on a signalized midblock crossing situated in Galle Road; Belek Kade Junction, Ratmalana.

The rest of the paper is presented as follows: Section II provides an overview of related prior research, Section III gives an insight into the pedestrian behavior on crosswalks, Section IV includes the proposed model, design and methodology of the system, Section V provides performance analysis with the discussion. Section VI concludes and finally with section VII predicts further research possibilities.

Related Work

The number of researches has been carried out in this regard; however, only limited attention has been directed for the problem of optimization of the existing set up of the crosswalk.

[3], has proposed a coordination control model for signalized midblock pedestrian crossing and adjacent intersections to enhance the efficiency of the arterial where common cycle length model was developed based on the original optimal cycle of pedestrian crossings and intersections. The work in [4] has carried out on the factors causing the violating behaviors of pedestrians at crosswalks. The researchers show that the ineffectiveness of the pedestrian crossing signal coordination time cycles as the main factor for violating the behavior of pedestrians at crossings. In [5] two approaches have been compared to predict collisions. 1. Model-Based Approach, 2. Learning-Based Approach and suggests that a deep reinforcement learning as the best approach as it is faster and inexpensive for predicting collisions with the highest level of accuracy [5].

Pedestrian Behaviour

According to the State Development & Construction Cooperation (SD&CC) in Sri Lanka, the typical speed of a pedestrian in Sri Lanka is about 1.66 m/s. That is, the pedestrian can walk nearly 1.7 m within one second. Table 2 presents the values for different categories of pedestrians.

Table 2. General crossing speeds of pedestrians with and without walking difficulty

Average	Speed (m/s)	Standard Deviation (m/s)	15th percentile (m/s)	50th percentile (m/s)	85th percentile (m/s)
Pedestrians with walking difficulty	1.35	0.08	1.14	1.29	1.63
Pedestrians without walking difficulty	1.70	0.15	1.31	1.60	2.04
All pedestrians	1.63	0.15	1.24	1.56	1.96

Belek Kade crosswalk is of 20 meters in length and is allocated with a fixed timer of 20 seconds for pedestrians to cross. Our research objective was to provide an optimal period depending on the different types of pedestrians waiting to cross the road.

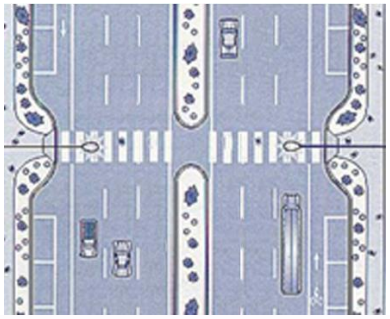

Fig. 1. Top View of the chosen crossing at Belek Kade, Ratmalana

The Belek Kade crossing encounters with three vehicle lanes from each side as shown in the above Fig. 1.

Methodology

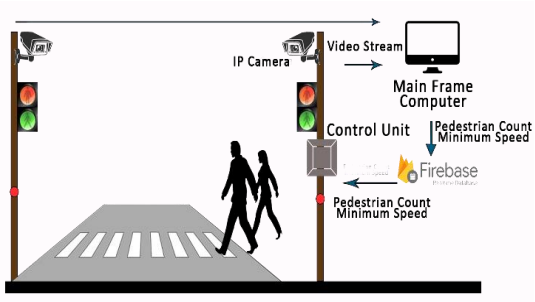

Fig. 2. Research Design

A. IMAGE PROCESSING ALGORITHM

This study was mainly based on the use of image processing where a live feed of pedestrians waiting to cross the road at a crosswalk was obtained. The setup is depicted in Fig. 2 above. A pedestrian is identified by a "bounding box" through the image processing algorithm. If more than one pedestrian is present, then each of them was identified by individual bounding boxes to obtain their unique speeds respectively. This real-time data was stored on an online database (Firebase Realtime Database) while being updated every 2 seconds onto a mainframe computer.

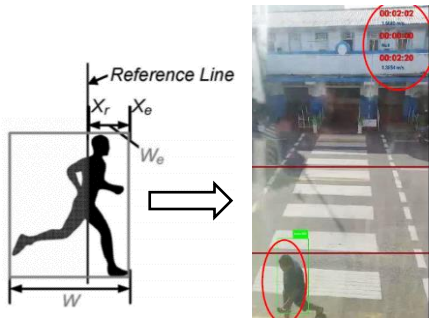

Fig. 3. Bounding Box Notation for the pedestrian crossing event

In reference to Fig. 3, Xe is the X-axis value of the right edge of the pedestrian's bounding box, Xr is the X-axis value of a vertical reference line and W is the horizontal width of the bounding box.

Depending on the pedestrian count, the average speed was obtained which is the minimum speed (i.e. the slowest pedestrian).

Fig. 4. Various cases of cropped training samples, with different entering angles/directions

B. SIGNALING MODEL

The existing time allocation system follows a method, that, for any pedestrian crosswalk, the crossing width is measured in meters where one meter is equivalent to one second. Hence, most of the crosswalks in Galle Road are allotted with a crossing time of 20 seconds. We were constrained to not increase the allocated time interval for crossing by traffic controlling authorities as it would add an extra burden on vehicular traffic. Therefore, the upper limit of

crossing time was 20 seconds. Data was collected at the Belek Kade Junction crossing where groups consisting of less than 6 people were randomly observed at peak (12:00 p.m. -2:00 p.m.) and off-peak times (10:00 a.m. – 11:00 a.m.) where a maximum of 18 seconds were taken by the pedestrians to finish their crossings. Based on this observation, a simple model was designed to control pedestrian crossing time based on the pedestrian densities at the crossings.

Thus, a simple logic was established that if the number of pedestrians is less than or equal to 5, the crossing time should be 18 seconds and if the number of pedestrians is more than 5, the crossing time should be changed to 20 seconds.

Graphs in figure 4 and figure 5 below indicate a normal distribution obtained by plotting the probability of occurrence of the duration of time vs. time in seconds.

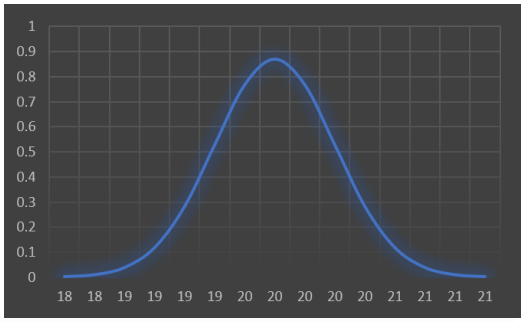

Fig. 5. Graph shows the variation when the no. of pedestrians waiting to cross is 6 or more

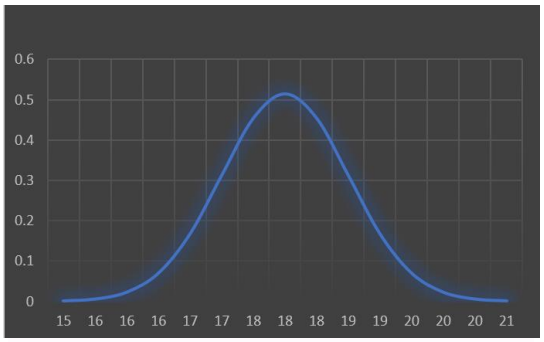

Fig. 6. Graph shows the variation when the no. of pedestrians waiting to cross is less than 6

C. CONTROL UNIT

In order to control the system, a microcontroller (Raspberry Pi 3B+) was utilized along with the controlling PLC. When a pedestrian comes into contact with the push button, after allowing 60 seconds in the green phase of the vehicle cycle, a 15 second timer begins inside the microcontroller. In the last 5 seconds of that, the real time pedestrian data uploaded to the database via the image processing system and gets downloaded by the microcontroller. According to the downloaded data, pedestrian crossing time was calculated and the calculated time was sent to the PLC. In the last 2 seconds of the timer, a Wi-Fi SSID begins to broadcast to alert the driver of a crosswalk ahead via the mobile app which is also made to emit from the microcontroller.

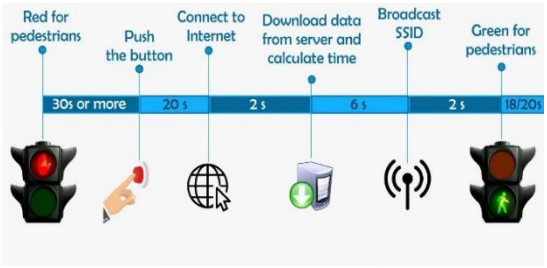

Fig. 7. Timing Cycle

D. DEVELOPMENT OF MOBILE APPLICATION

A mobile application was designed for the purpose of alerting the motorists of a crosswalk ahead. This background running app was developed using Android Studio 3.1.3 and does not require any network connection in order to be activated.

The detection process happens via a SSID emitted from the Raspberry Pi module where the app was rendered to identify this SSID as a Wi-Fi hotspot via the driver's mobile phone. Once this detection occurs, a sequence of continuous "beep" sounds was set to go off acknowledging the motorist of a possible crossing ahead.

The objective of creating an app was to make sure the driver slows down and eventually stops before a certain crosswalk. The app also aids as an

additional tool for the conservative signaling system.

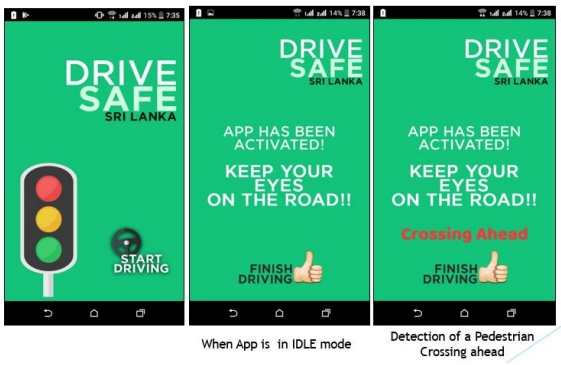

Fig. 8. "Drive Safe" Application Interface

E. ANYLOGIC SIMULATION MODEL

AnyLogic is a multimethod simulation modeling tool developed by The AnyLogic Company where it supports agent-based, discrete event, and system dynamics simulation methodologies.

AnyLogic includes a graphical modeling language and allows the user to extend simulation models with JAVA code through custom model extensions.

It can specifically be used to simulate pedestrian dynamics and road traffic situations.

Results

To show the applicability of the suggested model, the following results were obtained after simulating the existing pedestrian light controlling model and the suggested model using the AnyLogic simulation software. This simulation was based on the extensive data obtained at the Belek Kade Junction pedestrian crossing as the experimental setup.

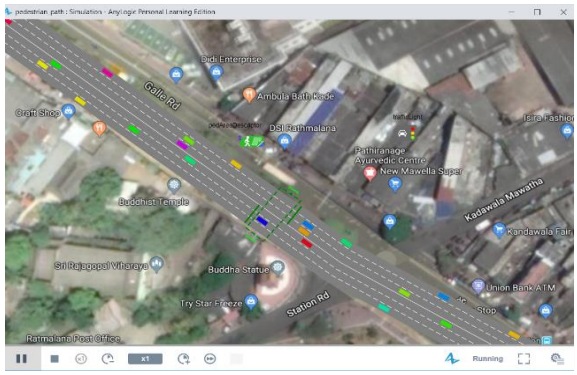

Fig.9. Vehicle queue density obtained using AnyLogic Simulation

These results show that the vehicle queue density (y-axis) during the observed hours of the day (x-axis) for the current model and the suggested model.

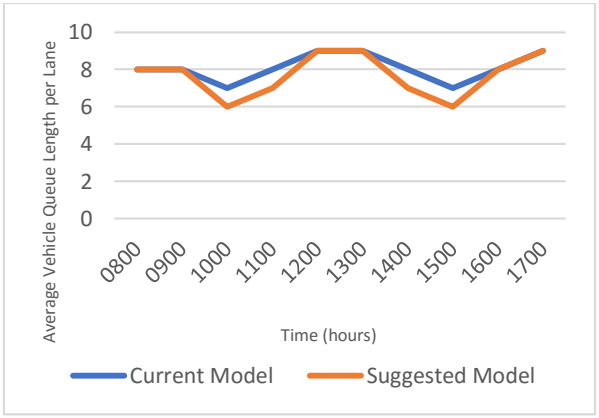

Fig. 10. Vehicle queue density in each lane from Colombo to Moratuwa

Thus, from Colombo to Moratuwa lane, a slight reduction in queue length was observed during certain off-peak hours from 9.30 am to 11.45 am and from 1.30 pm until 3.50 pm.

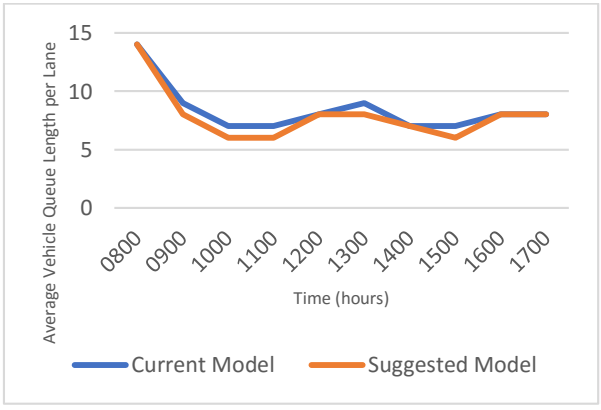

Fig. 11. Vehicle queue density in each lane from Moratuwa to Colombo

From Moratuwa to Colombo lane, a slight reduction in queue length was observed at some off-peak hours from 9.00 am to 11.30 am, from 12.00 pm to 1.30 pm and again from 14.15 pm until 16.00 pm.

Conclusion

The analysis of vehicle queue density reveals that vehicle traffic can, in fact, be reduced during certain off-peak hours by utilizing the proposed model. The pedestrian safety issues on the road can be mitigated using a driver alarming system as it assists in directing the driver's concentration more towards the road and pedestrians, during the approach. Pedestrian collisions like other road accidents should not be accepted as inevitable because they are, in fact, both unpredictable however avoidable if correct preventative measures are taken. Hence, it can be concluded that this research is indeed an area of great opportunity to be explored further and results will provide greater efficiency, safer roads for pedestrians as well as for vehicle users.

Future Works

The work is in progress to extend the utility of our research under the following aspects:

a) The existing app is enhanced to aid for differently abled pedestrians with severe visual impairments, in order to assist them in crossing the road more safely and without any assistance.
b) Development of an augmented reality application to display across a certain alert patterns to direct the driver's attention.

Acknowledgment

The authors wish to thank Eng. SU Dampage for giving us a valuable guidance, stimulating suggestions and encouragement to coordinate our project from the beginning to the end at every necessary moment. The authors also would like to acknowledge with much appreciation for the support and guidance provided by the state development and construction cooperation (SDCC).

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Effect of Size and Position of Pinholes on Transformer Core Loss

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Abstract: This paper presents the investigation of the variation of core loss due to the effect of pin holes in the transformer core which are used to stack the core sheets in a step lap pattern. A three-phase distribution transformer with a rating of 160 kVA, 11 kV/ 415 V has been selected for the investigation. The transformer model was developed using SolidWorks software and examined for the no-load loss using finite element analysis software ANSYS Maxwell. Simulation results were obtained for different pin hole sizes and positions. The flux variations in the core, with and without pin holes are analyzed. Based on the core loss, the optimum pin hole diameter and positions are determined. Analysis shows that the hysteresis loss is not significantly affected by the pin holes while the eddy current loss has an effect from pin hole diameters. Analyzing the results, the optimum pin hole diameter is determined as 6 mm corresponding to an increased loss of under 1% of the loss. Results further show that placing the pin holes where the flux distribution is a minimum, reduces the core loss. The results of the analysis are planned to be implemented in an actual distribution transformer.

Keywords: transformer core, core loss, core stacking, step lap, pin hole

Introduction

Power system reliability mainly depends on the efficient working of the power transformers which are key components in the power system. Estimation of the core losses in the transformer is a vital issue, and has to be implemented in the design stage of the transformer. Accurate prediction of these losses is becoming more important in the design and also in the economic aspect [1].

In the transformer, a combination of hysteresis loss and eddy current loss is the main contributor to the core loss [2]. It is initiated by the magnetizing current required to energize the core of the transformer. The magnitude of the eddy current is reduced by using laminated sheets insulated from each other. Laminations are lapped to avoid air gaps developing in the magnetic core. Of the two methods of lapping commonly used in distribution transformer cores, the step lap joints are considered superior to the butt-lap joints when considering the magnetic characteristics such as magnetizing current, core losses and noise level [3]. The material used in the manufacturing of the core is grain oriented electric sheet steel with Silicon around 3% by weight [3]. The grain oriented laminations have to be precisely aligned to get the maximum benefit. Thus pin holes are made in the laminations to aid aligning. These pin holes increase the core loss. If the pin holes are made very small the aligning pins would bend, so that they need to be of a minimum size. The position of the pin holes will aid the alignment when placed in the middle, but shifting it away from the main magnetic path would reduce the losses.

Thus the present study examines the practice of the currently used sizes of pin holes and their positions with regard to the magnetic field and the corresponding core loss.

Arrangement of the Transformer Core

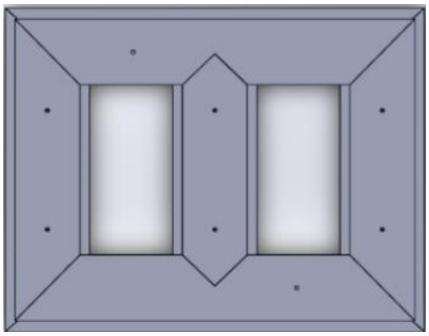

Fig. 1. Surface view of 3-phase Transformer with solid stacks

Initially, a three-phase transformer, with three solid stacks, shown in Fig. 1, was designed to actual dimension (used in LTL Transformers) of 160 kVA, 11 kV/ 415 V transformer using SolidWorks software with the actual positions of the pin-holes shown in Fig. 2.

The cross-section of the core with three stacks of different widths are shown in Fig. 3 and the holes and slots used as guides during assembly of the core are shown in Fig. 4.

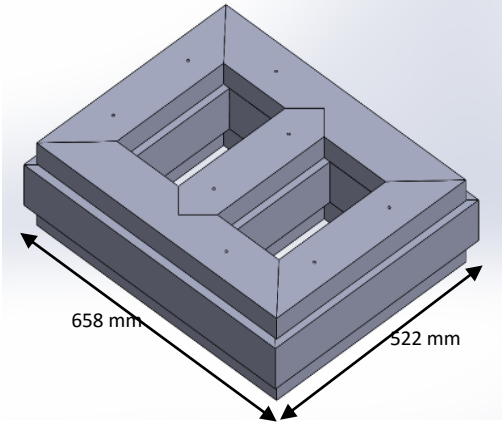

Fig. 2. Actual positions of pin holes

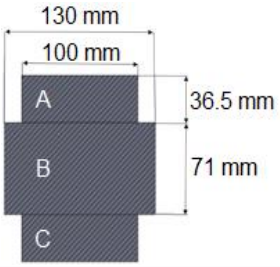

Fig. 3. Cross sectional view of a limb of the experimental core

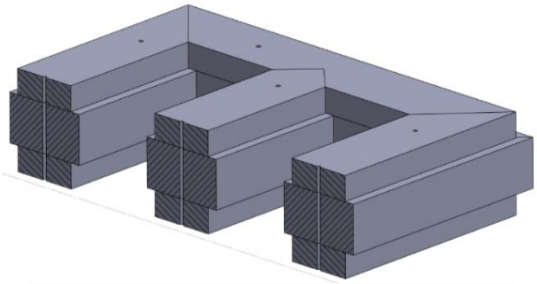

Fig. 4. Cross sectional view of the core with three stacks of solid

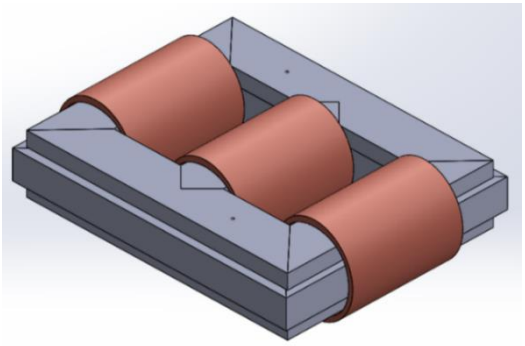

Fig. 5. Transformer core with windings

Since the purpose of the study is to determine precisely the flux paths and the corresponding losses in the core, only a single energized winding per phase was considered in calculating the core loss as the other winding would normally be kept open during the test. The low voltage winding of copper foil was accordingly designed using SolidWorks and the Transformer core with windings shown in Fig. 5.

A. Different pin hole diameters

The transformer core was designed for no pin hole and for varying pin hole sizes of 4 mm, 6 mm, 8 mm, 10 mm, 12 mm, 14 mm, 16 mm and 60 mm diameters to observe the core loss variation and flux distribution of the transformer with the pin hole sizes.

B. Different pin hole positions

For the calculation of transformer core loss for different pin hole positions, models were developed with varying pin hole positions from the original transformer model. Fig. 6 shows the designed models for the varied positions for 6 mm diameter pin holes and Fig. 7 shows the varied positions for 10 mm diameter pin holes.

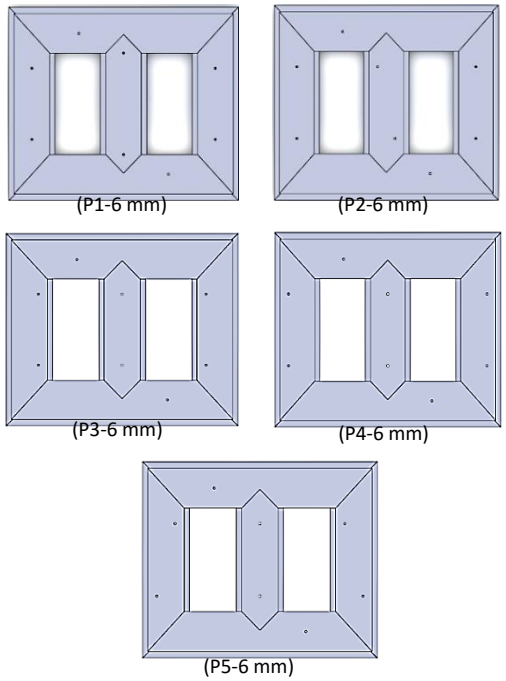

Fig. 6. Proposed positions for 6mm diameter pin holes

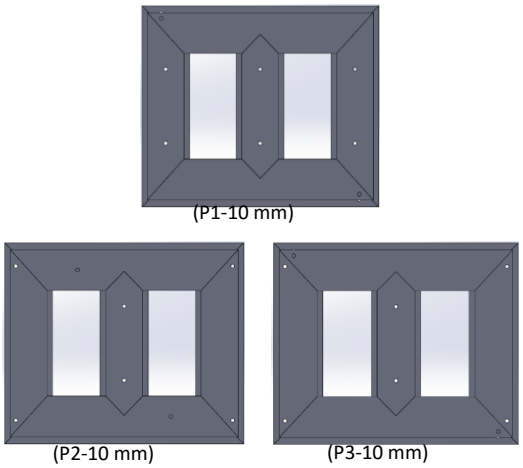

Fig. 7. Proposed positions for 10mm diameter pin holes

Methodology

ANSYS Maxwell, a field simulation software based on finite elements was used to study the time varying electromagnetic fields in the transformer core. The automatic adaptive mesh generation available in the software removed the complexity from the analysis process [4] and presented in the Fig. 8.

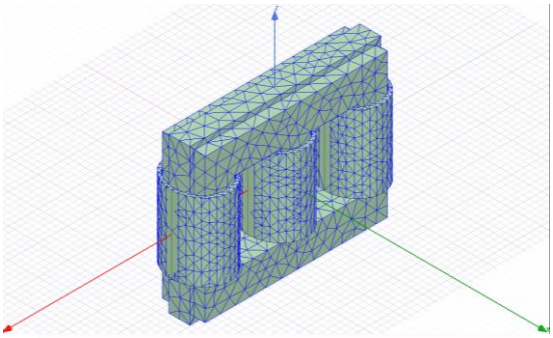

Fig. 8. Mesh plot in inside selection/ Length based operation

A higher mesh resolution has been used in regions where accuracy is important and to obtain reliable computed results. As adaptive mesh refinement is possible in Maxwell static solvers, the required level of accuracy has been achieved. For core loss analysis, only a low voltage winding is considered in each limb as no load test is done by open circuiting the high voltage side of the transformer. Actual voltages, and winding resistance values were assigned for all three windings and results were obtained for a defined time period for the transient simulations.

The material used for the core is 27ZH100 silicon steel and by assigning a lamination factor, the same effect of the laminated core can be obtained for the solid stacked core. Fig. 9 and Fig. 10 show the B-H (Flux density - Magnetic force) curve and B-P (Flux density - Specific core loss) curves respectively for this material.

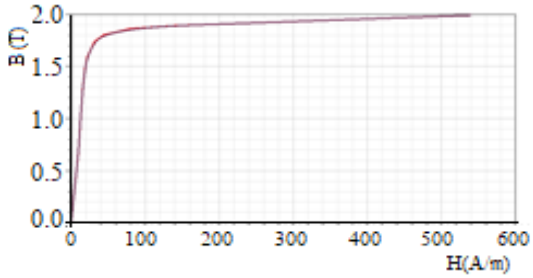

Fig. 9. Flux density (B) vs Magnetic force (H) curve

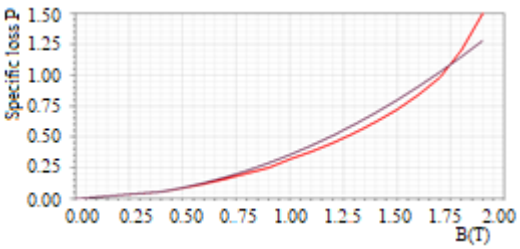

Fig. 10. Specific core loss (P) vs Flux density (B) curve

Results Analysis

Flux distribution of the transformer core with, without pin holes and different positions of pin holes were analyzed using the results of the simulations using the ANSYS Maxwell Software. Time variations of input voltage, induced voltage and current curves for low voltage winding were obtained. The obtained time variation of core loss graph includes hysteresis loss and eddy current loss and the obtained core loss was averaged over 100 ms to 120 ms.

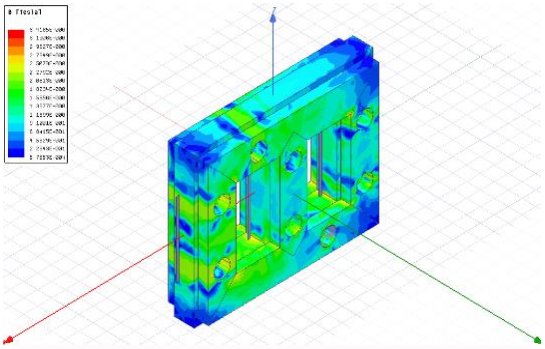

Fig. 11. Flux Distribution in Core with 60 mm diameter Pinholes

To understand how the pinhole diameter impacts on the core, and validate the analysis, loss, an exaggerated 60 mm diameter pinhole was designed, and the flux distribution seen in Fig.11. It can be observed that either sides of the pinholes have a dense flux which express that the pinholes have been considered correctly in the simulation. Fig. 12 shows the deviation of the arrows (showing the direction of the flux) near the pinholes showing the effect of pinholes for the flux distribution.

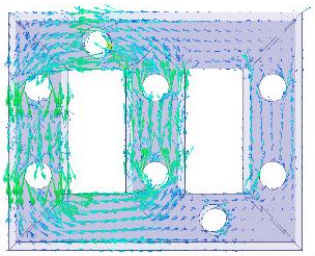

Fig. 12. Vector diagram of flux distribution of core with 60mm diameter pin holes

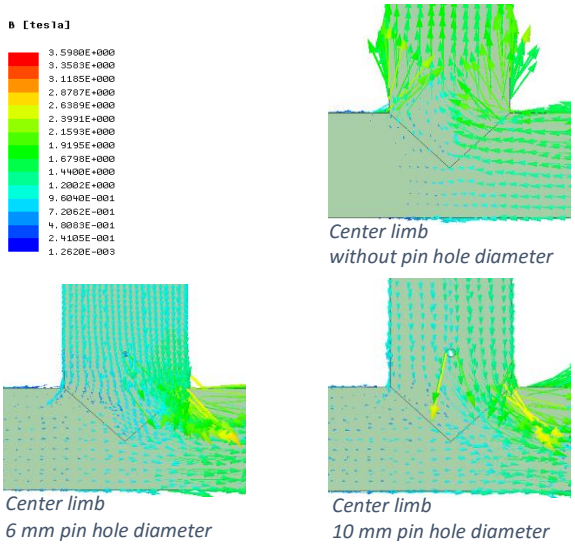

Fig. 13. Flux distribution in center limbs with out pin holes, with 6 mm and 10 mm diameter pin holes

Fig. 13 shows the flux distribution in the centre limb in the absence of pin holes, and in the presence of 6 mm and 10 mm diameter pin holes. It is seen that the flux distribution near the pin holes shows a slightly visible deviation. It is obvious that when the pin hole diameter increases, the deviation of the flux path is also high. Similarly, it can be seen that flux path is disturbed in the core limbs with pinholes than the core limb without pin holes. Colour of the flux lines can be read by using the colour bar and the flux density value that obtained was 1.76 wb/m^2.

Using the standard EMF equation of Transformer given in equation (1), the flux density is determined.

$$\mathbf{v = 4.44BAfT} \qquad (1)$$

where; v - Voltage (rms)
B - Magnetic flux density

A - Cross section area of a core limb
f – Frequency
T - Number of turns

$$B = \frac{415/\sqrt{3}}{4.44 \times (16530 \times 10^{-6} \times 0.95) \times 50 \times 39} \quad (2)$$

$$B = 1.76\ \text{Wb/m}^2$$

(A has been multiplied by a factor of 0.95 to represent minute air gaps that may be present in between laminated sheets.)

The input voltage graph and induced voltage graph are shown in the Fig. 14 and Fig. 15 respectively.

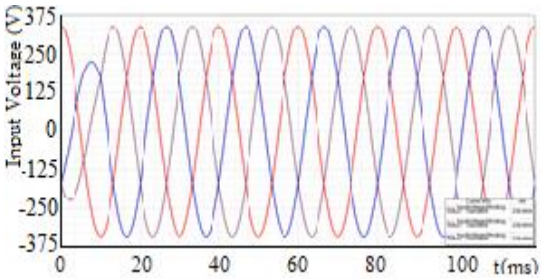

Fig. 14. Input voltage versus Time

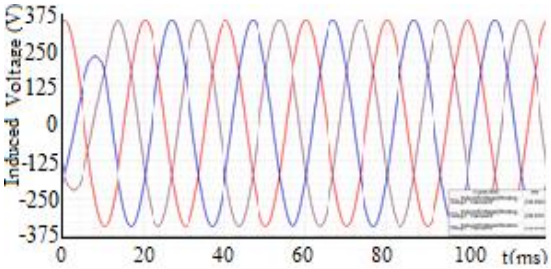

Fig. 15. Induced voltage versus Time

E. Pin hole Diameter

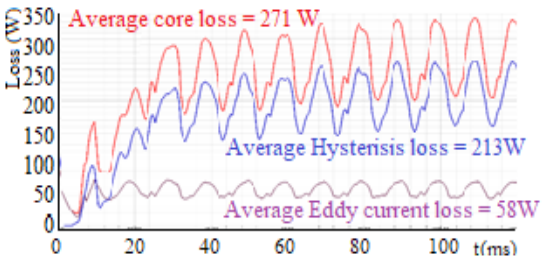

Fig. 16. Eddy current loss, Hysteresis loss and Core loss versus Time for no pin holes

The Fig. 16 presents the time variation of core loss obtained for the core with no pin holes. The core loss is the summation of both eddy current loss and hysteresis loss, and it is observed that the eddy current loss is less than the obtained hysteresis loss. As per the results, a nonlinear increasing core loss was obtained.

Table 1 shows the percentage values of core losses with respect to the core without and with pin holes. Accordingly, quite a large difference can be observed between 6 mm diameter pin hole and the 8 mm diameter pinhole and, a smaller difference between the 8 mm diameter pin hole and the 10 mm diameter pin hole. The effect of the pin hole diameter on the transformer core loss can be clearly identified. It proves that the core loss has been greatly affected by the pin hole diameter.

Table 9. Percentage change Core Loss Variation for Pinhole Diameter

Pin hole diameter (mm)	Total Core Loss (W)	Percentage change (%)
0	271.2384	0
4	271.4972	0.095
6	273.7431	0.923
8	288.5775	6.392
10	300.0218	10.611
12	301.0507	10.991
14	302.2046	11.416
16	305.5936	12.666

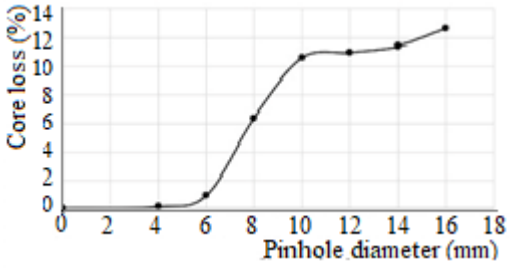

Fig. 17. Core loss variation for different pin hole diameters

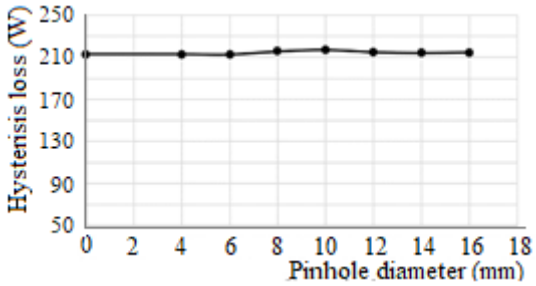

Fig. 18. Hysteresis loss variation for different pin hole diameters

Fig. 18 shows that there is hardly any effect on the hysteresis loss with the increase of pin hole diameters.

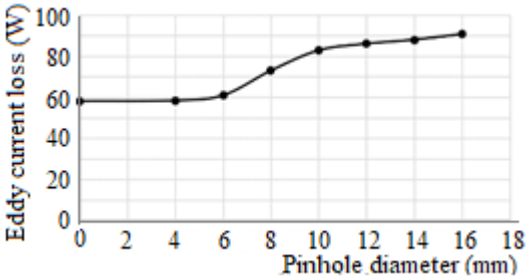

Fig. 19. Eddy current loss variation for different pin hole diameters

Fig. 19 depicts a significant effect on the eddy current loss with the variation of the pin hole diameter. In particular, it is noticed that there is no significant effect of the core loss (less than 1% of the loss) with pin holes of diameter upto 6 mm, and a significant increase thereafter.

Practically, the core loss for core with 6 mm diameter pin holes is obtained from the core loss curve for 27ZH100 material as,

Specific core loss = 1.1 W/kg
Weight of the core = 265.3 kg

Therefore, Core loss $= 1.1 \times 265.3 =$ 291.83 W

In the present simulation, only the core loss has been taken into consideration neglecting dielectric loss and copper loss.

Fig. 20 shows the induced current on the low voltage side in each winding for no pin holes.

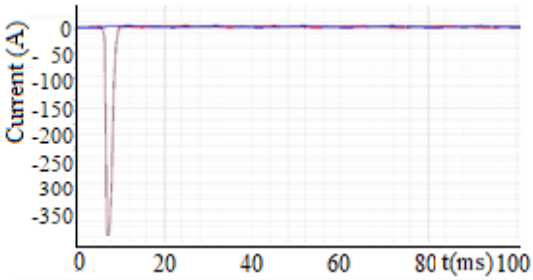

Fig. 20 Induced current in each winding with time for no pin hole

Table 10. Winding Current for different Pin hole sizes for single phase

Pin hole diameter (mm)	Current (A)
0	1.4228
4	1.456
6	1.6955
8	4.0834
10	8.5386
12	17.6709
14	26.4944
16	37.5703

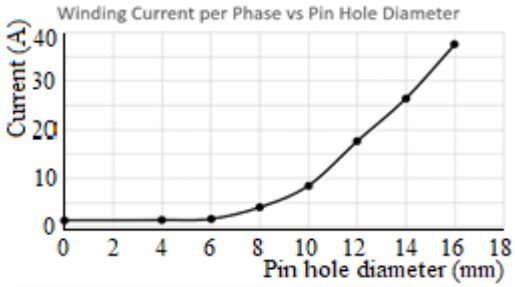

Fig. 21. Magnetizing current Variation for Different Pinhole diameters

Fig. 21 represents the variation of magnetizing current for pin hole diameters. As per the graph, only a slight increase in the magnetizing current is visible with pin holes of diameter upto 6 mm and a gradual increase thereafter. The fact is that the increase in magnetizing current means the increase in core loss which in here implies that the loss increases with the pin hole diameter as the magnetizing current increases. Thus, increasing pin hole diameter unnecessarily will leads to

increase of core loss. Accordingly, the pin hole diameter of 6 mm can be considered as the optimum pin hole size for the particular transformer core.

B. *Pin hole Position*

The positions of the pin holes were decided by considering the flux distribution in the core. As in the Fig 6, five different pin hole positions were selected for the core with 6 mm diameter pin holes. Fig 22 shows the variation of the core loss with the pinhole positions. It is noticed that there is no significant change of the core loss with the different positions compared to the existing position.

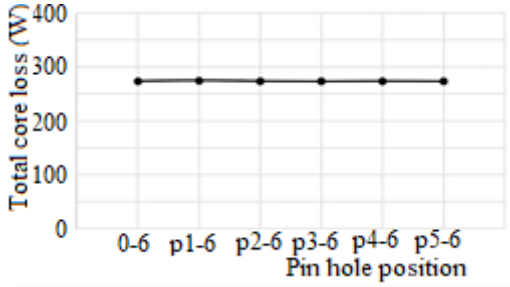

Fig. 22. Total Core loss variation for different pin hole positions of 6 mm diameter

For further analysis of the effect of the pin hole positions, a core with a greater pin hole diameter was selected and decided on various pin hole positions as in Fig. 7 where there is low flux concentration. The selection was done with the sole purpose of determining the effect of the pin hole position to the core loss without considering the mechanical strength of the core.

As the significant change was observed, it was able to identify that the pin hole positions affect the flux distribution and the core loss.

The Fig. 23 shows the variation of core loss with the change of pin hole positions for 10 mm diameter. According to that P0-10 is the position kept as the reference and other positions were the proposed positions to determine the effect. It can be seen that there is a specific variation in the core loss and it is graphed in decreasing order of core loss values. Thus, the position P3-10 can be considered as the optimum pin hole position where there is a lesser core loss. The reduction of magnetizing current variation with the pin hole positions further implies the variation of core loss which is not mentioned here. But this result is valid only to determine the effect of pin hole positions to the core loss and it may be not practical in manufacturing.

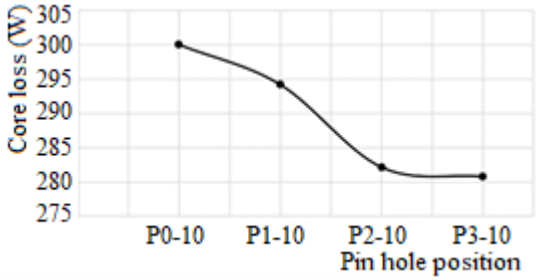

Fig. 23. Total Core loss variation for different pin hole positions of 10 mm diameter

Conclusion

The paper has presented an analysis of the variation of the core loss with the size and position of the pin holes in the stacking of step-lap transformer cores.

For a 160 kVA, 11 kV/ 415 V 3-phase distribution transformer, by analysing the range of pin holes 0 to 16 mm diameters, the study has shown that there is a visible increase in the core loss (from 0.92% to 6.39%) with the increase of the pin hole diameters from 6 mm to 10 mm. Further, the contribution of the pin hole diameter to the change of the hysteresis loss is negligibly small but has a significant effect on the eddy current loss.

When referring to the magnetizing current, it has been observed that the 6 mm diameter pin hole is also the optimum pin hole size, as up to that value gives a very low currents and rapidly increasing values as the current increases beyond 6 mm.

When different pin hole positions are considered, for small pin holes, the pin hole position has very little effect on the core

loss compared to the normally used pin hole positions of the same diameter. But with 10 mm diameter pin holes, the changes in the pin hole positions show a significant variation in the total core loss compared to the existing pin hole positions of the same diameter pin holes. Hence it is clear that when the diameters of pin holes increase, the effect for the pinhole positions is greater and thereby it affects the total core loss. This further verifies the suitability of the core with 6 mm diameter pin hole size as optimum for the selected transformer.

In modelling a transformer, both practical and theoretical issues should be considered. For the 160 kVA transformer considered, the optimum pin hole diameter is 6 mm although the lesser diameters give a less core loss, smaller pin hole sizes will be difficult to handle. The increase in percentage core loss of the core with 6 mm diameter pin holes with respect to the core without pinholes is about 0.92%, which justifies the use of 6 mm diameter pin hole.

With regard to the position of the pinhole, with the 6 mm pin hole, position has very little effect. However positioning should preferably be in the low flux region for larger pinhole sizes than 6 mm. However in manufacturing a transformer as per the suggestions, the mechanical strength and the life expectancy should be assured atleast to the extent achieved in here.

Acknowledgement

Excellent completion of the project became a reality with the kind support and help of many individuals. We would like to extend our sincere thanks to all of them. Also, our gratitude goes to all academic and non-academic staff of the Electrical, Electronic and Telecommunication department of General John Kotelawala Defence University. We are very grateful to management of LTL Transformers (Pvt) Ltd for giving us immense support on providing test data and all the relevant details of distribution transformers.

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Paper ID 361

Intelligent Security Robot for Warehouse Security ("WATCHMATE")

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Abstract: Robots are already playing a major role in human life. With the development of technology various types of robots have been built up to apply in different fields. i.e. security, healthcare, education, military etc. With the current security condition in Sri Lanka following the explosions which occurred in several places in the country, security has become the most important factor helping the civilians to continue their daily routine. To ensure the security of places, security personnel play a vital role. Since they are aided by CCTV camera system, if there is some unauthorized incident the only action which can be taken is only by the security team. Hence, they risk their lives to ensure the maximum security. But as the cost of a life cannot be redeemed, an option to reduce the damage that may happen to security personnel must be thought of. The present research focuses on a machine-based solution for this, and this system is named WATCHMATE. It is an intelligent system which can act as an assistant to the security guard in detection and neutralization of an intrusion with remote control.

Keywords: Motion detection, Security, Intelligent system, Remote control

Introduction

Security robots are kind of machines which are designed to gain maximum security in many fields such as transportation, military, healthcare, business environments like shopping malls etc. Traditionally, security robots are designed to monitor the environment for a security threat and to notify the necessary persons through alarms or notifications but not to take actions required to neutralize the threat. Although there are robots with weapons developed for the military arena it is difficult to find a robot with a weapon designed to engage on other fields. Security means the safety, as well as the measures taken to feel protected from harm. Security does not always concern about the human safety; it also concerns of material safety as well as the safety of properties. In warehouses all these aspects must be considered in means of security. Most common security measure taken these days is the installation of CCTV cameras. CCTV cameras can be used to monitor an area interior or exterior through videos by transmitting signals to a PC monitor or a set of monitors. Intelligent system is a system which is capable of monitoring and sensing the changes happen around it and taking necessary actions on real time by the system itself. Theodora's Theodoridis and Huosheng Hu (2012) conducted a survey to claim what defines an Intelligent Security Robot (ISR) and what are the characteristics that make a security robot intelligent. The two parameters which defines ISR are perception parameter and action parameter. The perception parameter incorporates the robot's realization of its environment, dynamically occurring events, and the acquisition of features via a ground-truth fashion. On the other hand, action parameter involves decision making and actions taken by the

robot in an autonomous fashion. Project WATCHMATE was built as an Intelligent Security robot which could replace human security guards engage in emergency fields such an unauthorized intrusion. The name WATCHMATE was selected with the meaning of Security Assistant (WATCH - MATE) Project suggests a system which can respond to the changes in the environment and notifying of those changes to a responsible party to take required next steps. Most importantly system will be composed of techniques to neutralize a threat remotely.

Methodology and Approach

G. Modular Design

The research project commences by solving the problems which have been identified within security required infrastructures such as Warehouses. Following figure shows the flow chart of methodology.

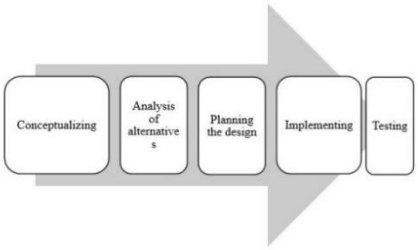

Figure 1. Methodology flow chart

Design contains 4 modules.

v. Intruder identification and notification system.
vi. Intruder neutralizing system with high accuracy.
vii. A rover with high mobility.
viii. IoT Based Sensor system. (Temperature, Gas level)
ix. Remote control system

H. Intruder identification and notification system.

An intruder is anyone who does not has authorised access to the premises and behaving suspiciously within the environment. Intruder identification and notification system is responsible for monitoring the area to detect intruders and notifying about them on real time when an intrusion occurred. High accuracy and low latency are expected from this system if not, false notifications and delay of conveying them will mislead into security breaches. In regard of this requirement CCTV camera systems already exists which can transfer live video streaming to a monitor. But they do not facilitate with detecting or notifying about an intruder. To detect an intrusion via a CCTV system someone needs to keep a constant eye on what monitor displays. Hence a system capable of detecting and notifying an intrusion must be introduced. To achieve this target, a new camera system sensitive for motions was implemented. This specific camera system can take pictures of an intruder who entered the premises within restricted hours and forward that picture to a responsible person through email. Hence the notification requirement is fulfilled.

Figure 2. Intruder identification and notification system

I. Intruder neutralizing system with high accuracy.

Once an intrusion detected, neutralizing the intruder with minimum life threats is another objective to be satisfied. For that a weapon system which would not take the life of intruder but neutralize him for some time should be developed by considering the following facts.

• Must be able to cover at least 180^0 in horizontal plane

• Must be able to cover 90^0 in vertical plane
• Accuracy should be maximum
• Autonomous and manual modes
• Fast switching between manual and autonomous modes

Figure 3 Intruder neutralizing system

A rover with high mobility

Rover is the actual engaging element of this project. The weapon system to neutralize an attacker, a camera to support the navigation of the rover and other controlled devices are required to be mounted on this rover. Therefore, the rover must be designed support all of those and required to meet up with the following requirements.

• High mobility
• High controllability
• Durability

This rover is going to be controlled and navigated remotely with the support of real time video streaming. Hence a camera appropriate for the purpose would be used.

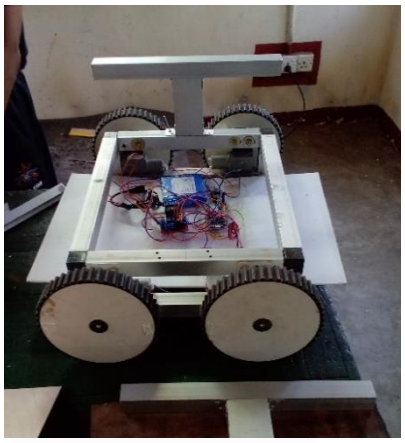

Figure 4. Four wheel rover

D. Iot based Sensor system

For real time monitoring of the environment a camera is not enough. So, Sensor system must be implemented on the robot. So, the user can real time monitor the temperature and gas level of the environment. So, if there is a fire or gas leak in the environment the user can identify it and get required action.

We used DSD11 temperature and humidity sensor for the rover to sense more data. This sensor is very accurate due to its classifications.

• Temperature Range: 0-500c
• Humidity range: 20-80%
• Operating Voltage: 3-5v
• Maximum current during Measuring:

2.5mA To get the feedback of the sensor we use nodemcu inbuild Wi-Fi programming board.

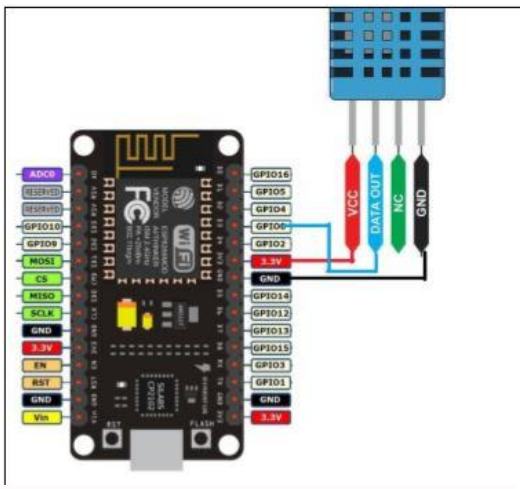

Figure 5. Circuit diagram of temperature sense system

We used MQ2 sensor to detect the gas. If there is a gas leakage robot can detect it and give a feedback. • Detection range: 300-10000ppm

• Target gas: Flammable gases
• Output Voltage:

2.5-4v MQ2 sensor is connected with the nodemcu board to take feedback to display.

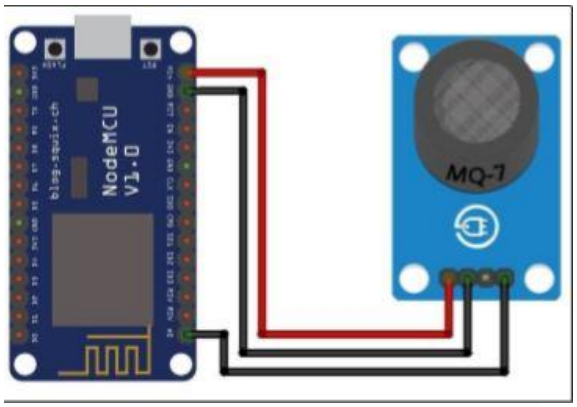

Figure 6. Circuit diagram of gas sensing system

E. Remote control system

After implementing the system remote access to the system should be enabled. So that the system could be controlled remotely at anywhere in the world. The application used for that purpose must be precise and user friendly. Remote desktop is such an application which could be used to access and control the robot remotely through internet. In this application it is essential of implementing a secure and reliable connection for the better performance. Thus, the connection must be encrypted appropriately.

F. Final Design

After assembling all the above mentioned systems a robot system with the capabilities of detecting and neutralizing an intruder

Figure 7. Final design of the robot

Test and Results

The Robot was tested after the implementation. While testing we obtained following observations,

• The Robot is taking 32 seconds to move 10m in linear direction.
• The Robot is taking 10 seconds to rotate one round around own axis.
• In the weapon system It rotates 1700 in X axis (pan) and 850 in Y axis.
• It is taking 2 seconds to activate trigger.
• Weight of the robot is 4kg.
• The Intruder notification system is taking 6s to take a picture and send an email.
• The Distance between a point in camera feed and actual target position is 5cm.
• The latency of the connection was highly affected for the performance of robot

According to above observations following test results were concluded.

• The speed of the robot is 31.25cm/s.
• Error – 5 cm.
• Latency depend on the connection speed

Application and Implementation

The purpose of this project is to explore loopholes in current security systems in warehouses and to introduce an enhanced security system with minimized human interaction.

This robot must be capable to replace human security guard. Since human are the most intelligent and most sensible creature in earth replacing a robot with a human is much challenging. But in this project, we tried to reach a satisfactory level. So, we implemented Temperature and gas sensors in the system. So, the robot is dwelled with vision, hearing, smell, and touch. So, the robot is a satisfactory approach to replacing a human security guard with a robot.

Future Improvements

There are several further developments explicit through the work carried out and the experiences gained from the project. Suggestions for the future work are listed below

- Improving the system to be behaved in a fully autonomous manner with help of Artificial Intelligence and Machine learning technologies.
- Development of a mobile application for the controlling of the system.
- Development of the weapon system to cause less damage but to do the task in required level along with high accuracy to track and fire on a target.
- Implementation of a database to improve the intruder detection process including all the details of the people authorised to behave in the protecting environment along with face recognition and object verification technologies.
- Improvement of the remote logging system to work from anywhere with real time application.
- Development of the mobility system to move easily at any terrain with capabilities of climbing walls, stairs, and hills. Hence robot will move easily even in a battlefield.
- Development of fast switching mechanism with manual and automatic control, so the robot can be operated in both modes as per the requirement.
- Improving the system to be more efficient by developing a self-recharging mechanism. monitor and can neutralize unauthorized intruder while on anywhere in world.

Conclusion

The study of Intelligent security robot for warehouse security presented a developed prototype of the robot. The proposed system can replace security guards and minimizing the risks to the lives of security guards. System was proposed to design featuring detection of an intruder and taking necessary actions to the threat of intruder on real time action. For the neutralizing part of the project a weapon system mounted with the robot was suggested. Controllability of the robot is from anywhere with remote access to the robot. While preparing for the project, we have specified our scope to the protection of a warehouse environment in which security concerns must be at highest level in any establishment. So, the robot is decided to be develop matching to an indoor environment. During the planning process of the project we studied regarding the currently available security robots and the technologies associated in developing those products. In parallel with the technologies we studied about different programming languages, platforms to build up the systems, controlling mechanisms, wireless communications models and then approached for the implementation of work. When proceeding with the project work, we faced several problems. To overcome some of those problems we had to follow up with the trial and error method. In building the structure of the robot we had to adjust the structure for several times in matching for the requirement. Wheels system assisting the mobility of rover had to be designed by ourselves even including brackets as we did not find them in the market matching

with our expectations. Another problem was what technology should be used to identify an intruder. There were several suggestions like use of a sensor node or use of a camera system with video processing ability are two of them. After analysing all options, we decided to build the intruder identification system with a Raspberry Pi camera which detect motions in both day and night and notifying them appropriately. MotionEyeOS was used to fulfil the requirement of surveillance. While working with Raspberry Pi we faced issues with serial port communication and proceedings were carried out by taking care of those issues as well.

The most important part of the project was developing of intruder neutralizing part. The weapon used in that task must met with several requirements and suggestion was to use a taser which will cause serious damage to a person's life. In the implemented prototype we used a toy weapon but in a real case implementation taser weapon could be applicable. For the control of the robot remote desktop application was used, so the controller can control the robot remotely from anywhere after at any time after receiving a notification or even without. Just required to have an internet connection and an appropriately installed remote desktop environment on your PC. Finally, we can conclude that project output is gained as the robot response in detecting, notifying and neutralizing an intruder. Mainly we could point out that robot can behave in the required process without a human engagement directly on the field to take actions against a threat.

Acknowledgment

We express our sincere gratitude to the support rendered by Department of Electrical Electronic and Telecommunication of General Sir John Kotelawala Defense University, and to our Squadron commanders, troop commanders, friends and comrades for supporting us.

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Paper ID 563

Design and Implementation of a Remote-Controlled Reliability Analysis and Energy Management System

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Abstract: The electricity distributed to any house, school, or industries comes from either Ceylon Electricity Board or Lanka Electricity Company (Pvt.) Ltd. Electricity is bought from LECO or CEB by its consumers under various criteria decided and defined by the Public Utilities Commission of Sri Lanka. These tariffs shall determine the cost to be paid for electricity by each consumer. Usually, due to faults within the consumer's electrical system within his or her property, the cost they have to pay is not actually the number of units that they consumed. This could be due to a faulty meter or even losses within the factory due to its machines. Power quality decreases due to many faults like this and also due to inductance. Therefore, they will have to pay for more than the units they actually have consumed. To overcome this, we could constantly monitor the system and bring about necessary solutions to fix it as soon as possible. However, doing this manually is tiring and requires the workers to constantly keep measuring the necessary parameters like current, voltage, power, frequency, and power factor. In almost all factories some machines will still be running idle when they actually not used. This project aims to develop an online energy monitoring system that can read data from the supply to factories and also machines and then display them on online application. This will also have the ability to notify on a phone or another app to remind someone to switch off or on any machine. Also, the project aims on carrying out a case study to have a thorough understanding of the factory Randhi International (Pvt.) Ltd., to help in deciding on what solution should be put forth to decrease power loss in any factory the user considers. These guidelines are presented as a case study and will be made into a generalized guide.

Keywords: Energy Management, Energy Monitoring, Loss Calculation

Introduction

In the modern world, demand for power systems has increased rapidly. Sri lanka is a developing country, where its demand for energy has increased at a fast pace over the past decades. Because of the cost of peak generation, electricity charge for the consumers will increase. Management of an energy system is very important in reducing the cost of electricity especially in commercial and industrial fields. In Sri Lanka energy conservation in commercial and industrial fields are poor. Managing energy systems require a very good knowledge in electrical, electronic and information technological fields. Due to its complexity and lack of knowledge of people on this field, they do not tend to initialize major steps in conserving energy. But with such system, production factories with high power consumption machinery would benefit.

In order to overcome this problem, we have come up with a system for companies which has the need to save power and reduce the electricity cost. This system is capable of controlling and analyzing the machinery and the power system of a company online, Specialty of this system is that the system can be controlled remotely

and its data would be saved for reliability analysis and further adjustments and developments. Information on the factory will be sent periodically (as it is required) to the operational person or anyone who is in charge. And the status of the factory will be sent to their mobile phones or computers and it will indicate the current consumptions, faulty machinery, idling machinery and many more. So as per their requirements they would be able to remotely access the system and control it. As mentioned, our main aim is to be able to make energy management simple and easy through this design by monitoring energy systems online. Future generation of Sri Lanka would benefit from the energy that was conserved and would tend to develop more advanced designs to economically develop our country.

These systems may have their own drawbacks. Due to the use of high technological devices, initial cost of these systems can be expensive. But after the implementation of the system it would save energy and also reduce the monthly electricity bill.

Background of the Study

This project is industrial, as it involves the monitoring, analyzing, and managing the energy system of commonly factories that have large machines working for a long time. In factories like these, that is with large machines, the consumption is very high and also the loss can be very high. Energy is poorly managed in places like these. Therefore, a lot of money is wasted on energy.

In order to work on, apply and implement this project we have selected two factories. They are Matara Freelan (Pvt.) Ltd. and Randhi International (Pvt.) Ltd. These two factories consist of large machines and have poor energy management. Therefore, the project team shall focus on doing a case study to bring about a good solution for energy management, develop an app to monitor the energy system and also to analyze the reliability of the system.

A. Problem Statement

Many factories, almost all, use many machines that are vulnerable to power line disturbances. Many power electronic devices inject disturbances to the power line, such as harmonics and noise. These reason increases the loss of power and thus poor utilization of power. Therefore, the cost to be paid for electricity is very high.

B. Purpose of the study

To develop a system that can monitor the energy system of the factory. And conduct a case study for energy management. To develop an online desktop application to display information of the system and which can notify the electricians or workers through SMS or calls, enabling them to remotely control machines. And automatically analyze the reliability and make energy saving and monitoring easy.

C. Research Hypothesis

Availability of a controlling the power system in a software from can reduce the power usage of the factory. And automatically analyze the reliability and make energy saving and monitoring easy.

D. Significance of the study

This research project is important to reduce the cost of the power consumption of the industrial field. The outcome of this research project is the remote controlling software app and the case study. For the industrial field this will help them to reduce power usage and case study will help them to identify the fault.

III. METHODOLOGY

This explains the methodological framework used in achieving the objectives

of the study by focusing on the topics of designing, planning and implementation of the research. It covers all the approaches taken to achieve the implementation of remote-controlled reliability analysis and energy management system.

A. Research Philosophy

To address the problem of energy loss in industries and also for monitoring their usage remotely, we have proposed a solution. This includes a scheme that could monitor the energy online and also an energy management system. This system can feed into an online energy monitoring application, either a phone or a computer. The parameters that could be monitored are current, voltage, power, power factor and frequency. The system that we develop also can automatically carry out a reliability analysis for the factory and also detect faults.

B. Research Approach

The proposed model will consist of a power analyzer, with an in-built processor that can read data from the machines or the supply and give an output. This data that has now been processed will be sent to a Printed Circuit Board, designed by us will then transfer the data to a central computer or even a mobile phone. The energy monitoring is basically done via the PCB that enables us to make a connection between the analyzer and the application built by us.

In the application that we have built, the several parameters shall be displayed. Furthermore, it shall detect faults in the system and will notify the users through a text message.

We will also carry out a case study that will help us to decide on what steps should be taken to improve power quality in the factory that we consider. Later these data shall be used to make a generalized set of guidelines for any user to implement, if he/she needs to improve their power quality. This is mostly applicable for industries. For this to be done, the power loss will be calculated. Furthermore, the necessary calculations to achieve the desired power factor will also be done.

The project we are developing has three main parts:

i. Online Energy Monitoring
ii. Energy Management
iii. Reliability Analysis

C. Research Design

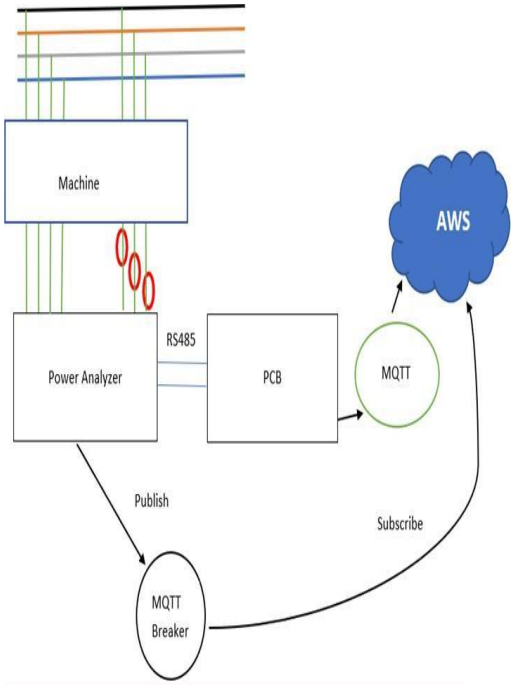

Figure 1: A figure showing the Research Design

Results and Discussion

Power quality is critical for the efficient operation of equipment. The power factor is a measure of the consumption of power by a particular company. Thus, by improving the power factor we can improve the quality of power to a great extent. The most common method of improving the power factor is to implement capacitor banks for power factor correction. The three main ways to implement capacitor banks in any organization are Global Compensation,

Individual Compensation and Group Compensation. Group and Individual compensation types are mostly followed. In factories they can follow individual compensation, fully group compensation or they can either follow a combination of both. This generalized solution was obtained from our case study. The results obtained in each of the areas are as follows:

A. Energy monitoring

In our application, the energy monitoring part is carried out by the installation of a power analyzer which is connected near the main supply and the test machine.

The voltages, currents, active powers, apparent powers and reactive powers, frequencies and power factors of the supply and machine are monitored in real time using this device. Through a custom-made PCB, information from the power analyzer is processed and sent to our mobile application wirelessly. This wireless network is made with a Wi-Fi module fixed in the PCB, which then communicates with the devices we have the mobile application installed.

Figure 2: The mobile application

B. Energy management

Energy management can be broadly defined as the proactive, organized, and systematic management of energy use in a building or organization to satisfy both environmental and economic requirements. Basically, it is the process of monitoring, controlling and conserving energy in an organization. Below diagram show the rescheduling loads for reduce the power usage.

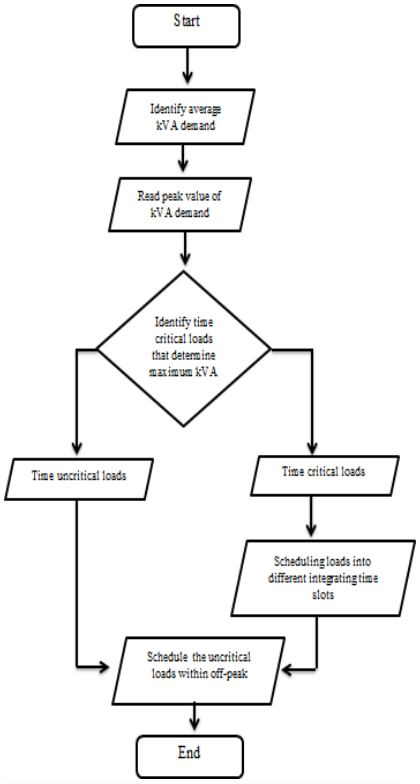

Figure 3: Energy Management flow chart

Acknowledgment

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POSTER PRESENTATIONS

Paper ID 24

Design of DC-DC Converter for ESP8266 Based IoT Sensor Nodes

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Abstract: In this article, we present a design of an improved DC-DC converter for low power Wireless Sensor Node using IoT. New research shows that the main drawback of future wireless sensor networks is energy storage, collection, and processing. WSNs are installed in remote locations and are powered by photovoltaic panels and batteries. In both cases, the power supply is variable. A DC-DC converter is a device that adjusts the source output voltage of a load. In this research, we have designed a DC-DC converter for ESP8266 based sensor nodes powered by battery. We have simulated the DC-DC converter using MATLAB with adding several protection and controlling features. This includes a PID controller for transient stability. This model output gives high efficiency DC power supply with very low ripple rate. Practically most of the failures in electronic devices occur due to power supply failures. This is the best solution for sensor nodes with long lasting life span.

Keyword: DC-DC Converter, IoT, PID Controller, Sensor Nodes

Introduction

IoT is a system which is used to remotely monitor and control physical phenomena in the environment. Mostly IoT is used for surveillance, agriculture, building automation, monitoring, military applications and tracking, etc. All the above applications the use of wired connections is practically complicated and thus, WSN is the most famous for the above-mentioned applications. In all the above situations, the most crucial necessity is to keep the sensor node alive, which means to keep sensor node without power failure, otherwise, that may affect the functionality of the entire system.

When we use a wireless device, the main requirement is the battery. For instance, if we use a mobile phone one of the major problems is battery capacity and running duration. That means our power supply should be highly efficient and sensor node energy consumption and operation algorithms have to have the capability to use microcontroller (sensor node controller) within its minimum energy consumption. Moreover, IoT systems uses expensive sensor and component, hence power supply should have to provide very smooth voltage and current for the protection of the sensor to avoid failure due to power fault. In this research, we design and simulate an improved and efficient DC-DC converter which can be used in such wireless sensor nodes.

Related Works

Several contributions are made on the DC – DC converter to power up wireless sensor nodes. Moreover, several electronic requirement manufactories publish their documentation focusing on product. Few recent works reported as below.

Himanshu Sharma, Ahteshamul Haqueand Zainul Abdin Jaffery have completed their research and survey for Solar energy

harvesting wireless sensor network nodes, which contains a brief comparison in between all DC-DC converter and designing guide to solar based converter design. The performance analysis is more useful to this design for selecting an optimum converter for this design [4]

WSN Power Consumption

First and foremost some commercially available sensor nodes were selected to obtain the power consumption of WNS. ESP32 which has low power system with Xtensa single/dual- core 32-bit LX6 microprocessor with integrated Wi-Fi and dual-mode Bluetooth was selected. The ESP 32 controller is shown in the figure 1 below.

Figure 8 ESP 32 chip

A. Load calculation

To obtain sensor node power consumption, the ESP 32 data sheet was used to calculate power requirement of this controller. ESP 32 is 3.3V controller but most of ESP32 board manufacturers include 5V to 3.3V regulator in their system. Pertaining to that the converter output voltage should be 5VDC supply. To obtain the required current the power consumption specification of ESP 32 controller was preferred, of which the details based on their data sheets.

The typical current is 240mA when 19.5dBm wireless power. However, normally with good Wi-Fi signal controller does not require that much power. Normally it is around 190mA power when 16dBm RF power consumption.

In addition to that we have to connect some sensor into this controller. For instance, if we interface DS18B20 temperature sensor it will consume maximum 4-5 mA. At the same time, we allocate another 50 mA to other sensor. Therefore the typical output current becomes 250mA. In ESP 32 data sheet advice that power supply current should be 500mA hence our power supply also has the capability to 500mA current. The finalized total power requirement is as follows.

Table 11 Load power consumption

	Min	Typ	Max
Output voltage (1% ripples)	4.9VDC	5.0VDC	5.1VDC
Output current	25mA (sleep mode)	250mA	500mA

B. Energy sources

As an energy source lithium battery was used. To select battery voltage, the preferred sensors were those which are capable of being used with the sensor node. Mostly, the supply voltage sensors (connect with sensor node) is either 5VDC or 3.3VDC sensor but in some special cases have to interface industrial sensor (12-24vdc). Generally Industrial level sensor operating voltage is 12 - 24VDC.

Pertaining to that, 12VDC is the most optimum voltage. In order to interface with that type of sensor, it can be directly energized using battery. As per previous load calculation 250mA is rated load. However, that power is not consumed at all times because when node is idle the controller operates in sleep mode. Therefore, the sensor node operation time was

arbitrarily selected as 8 hours while the same to be used for 5 days without intermediate charge.

$$Battery\ Capacity = \frac{V_{load} \times I_{load} \times T_{Working}}{V_{cell} \times DOD \times 0.8}$$

$$Battery\ capacity = \frac{5v \times 0.25A \times 8 * 2}{12 \times 0.8 \times 0.8} = 6.5Ah$$

Equation 1 Battery capacity calculation

Design and Implementation

The system consists of one DC-DC converter with controller and protection circuit. The design needs to fulfill the following basic requirements to be a preferred converter.

I. High voltage stability.
II. Prevent from over voltages.
III. Maintain low voltage and current ripple.
IV. Smooth operation in low power level.
V. High efficiency level (For long-lasting battery life)
VI. Small size

A. Converter switching frequency

The switching frequency may depend on the application. Normally the higher frequency gives following benefits,

I. Decreased ripple level
II. Improve dynamic performance
III. Smaller inductor and capacitor
IV. Decreased total physical size of the converter (smaller components)

The higher the switching frequency, the smaller are the inductor and capacitor needed, and a better dynamic.

ESP 32 microcontroller uses MHz range clock pulse. The selection of MHz range switching frequency might affect the controller as a power disturbance. Pertaining to that, the switching frequency was selected as 180 kHz which lowers the controller operation frequency and enough to keep dynamic performance and maintain switching losses as low as possible.

B. Buck (step-down) converter

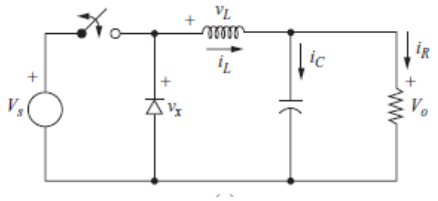

Figure 2 Buck converter circuit diagram

Initial design of DC to DC step down converter is shown in the above figure 2. Buck converter always produces low voltage level as the output compared with input (supply) voltage. In smooth dc/dc power supply output current is always greater than zero. Thus, the circuit is assumed to be operating in the continuous conduction mode. The converter input output equation is $V_0 = V_s D$ [3].

1) Inductor value

To calculate the Inductor value Equation 2 is used. In this circuit 20 percent (50 mA) Δi_L may be acceptable and further voltage smoothing is done by the capacitor. Practically the Inductor ripple current lies in between 20 to 40%.

$$L = \frac{(V_s - V_0)D}{\Delta i_L f}$$

$$L = \frac{(12 - 5) \times \frac{5}{12}}{0.2 \times 0.25 \times 180000} = 3.24 \times 10^{-4} H$$

Equation 2 Inductor value

To ensure continuous current operation in the circuit, the inductor value was increased by 25 percent. Furthermore, the value was rounded off to; $L = 5 \times 10^{-4} H$.

2) Capacitor Value

To calculate Inductor value Equation 3 was used. The voltage (50mV) ripple was assumed to be 1%.

$$C = \frac{(1-D)}{8L\left(\frac{\Delta V_0}{V_0}\right)f^2}$$

$$C = \frac{\left(1-\frac{5}{12}\right)}{8\times 5\times 10^{-4}\left(\frac{0.01}{5}\right)180000^2} = 2.25\mu F$$

Equation 3 capacitor calculation

Considering the market availability of capacitors, the capacitance was selected as C=2.2µF.

C. Initial DC-DC Converter Design using MATLAB.

The buck converter was designed using the parameters calculated above. The designed buck converter is as shown in the figure below.

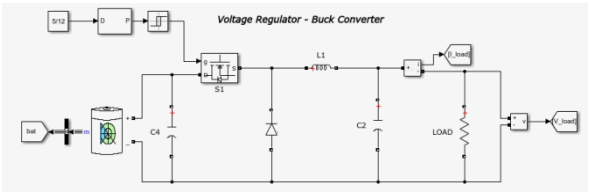

Figure 3 Initial model

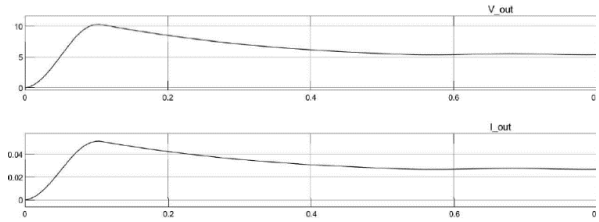

Figure 4 Voltage and current waveform

As per above figure, high voltage and current spike at the transient at period can be observed but circuit gives smooth 5V supply at steady state period. If this circuit is energized in an actual application, then definitely the sensor node will be damaged due to over voltage issue. To improve the transient stability and general protection scheme, the following function was added.

1) Good controlling system (PID) with Soft starting circuit rather that fixed PWM.

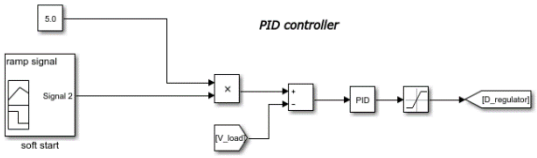

Figure 5 PID controller

In this research the brief explanation about controller was not included. After adding the above controlling circuit, the output waveform is as follows.

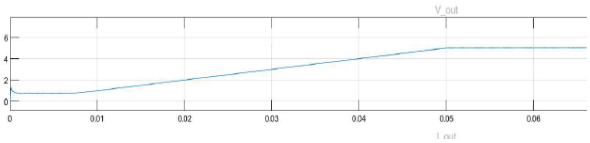

Figure 6 Output waver form after controller added

2) Over voltage protection – Crowbar circuit

The most valuable component in the sensor node is the sensors and the controller. Due to some faulty condition there was a high possibility to increase voltage up to battery voltage. To protect the circuit from over voltages, use the crowbar circuit at the output stage [1]. Crowbar circuit uses a thyristor and voltage sensing circuit. When the output voltage increases up to a certain amount the SCR was triggered. SCR is connected parallel to the output terminal of the converter. If SCR was triggered the output is instantly short-circuited via SCR. Pertaining to that, overcurrent protection was activated and the expensive elements were saved from over voltages. The output waveform and shunt SCR is shown in the figure 7 below.

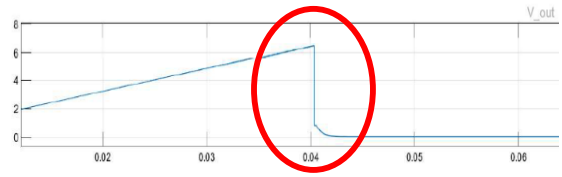

Figure 7 Overvoltage protection performance

3) Reduce high frequency ripples

Normally electrolytic capacitors have poor response to high frequency ripples. Pertaining to that ceramic capacitors were used in output stage since ceramic capacitors has greater performance in high frequency signals.

4) Battery protection circuit

To protect battery, form short circuit and other general hazard the following protection circuit was included to MATLAB model.

i. Battery under voltage protecting / over discharge – If battery over discharge during operation period that may affect to battery lifetime.
ii. Over temperature protection

If faults were detected by protection circuit it will suddenly reduce converter duty cycle to 0%.

Results

After adding all above feature into power supply model that will give very smooth output voltage with very low ripple rate nearly 0.66%. The output voltage waveform is shown in the figure 6.

The duty cycle variation of PWM signal for keep constant voltage is shown in following figure.

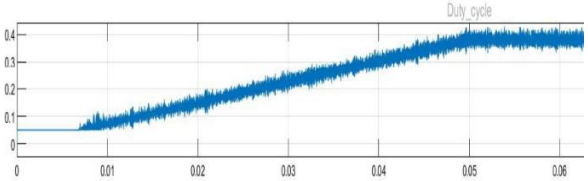

Figure 8 Duty cycle variation

Summary

We were able to come up with a successful design of DC-DC converter for ESP8266 based IoT sensor nodes. Two parameters were used to evaluate the above data which are voltage ripple and inverter efficiency. In practical situation, the sensor node works in different load condition as discussed previously. As per above values the converter gives best performance in 500mA load and nearly gives 94% efficiency in typical load.

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Paper ID 167

• Electrical and Electronic Waste Management in Sri Lanka

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.**Abstract:** E-waste or electrical and electronic waste is one of the fastest-growing waste in the world and this problem affects Sri Lanka as well. E-waste will become an emerging issue in the near future because the estimated e-waste generation in 2021 is 0.09 million tons in Sri Lanka. E-waste contains valuable compositions that have economic value when it recycled correctly. Unfortunately, Sri Lanka has not improved in e-waste recycle and e-waste management. Therefore the objectives of this research were to find out different types of e-waste generate in Sri Lanka, identify different compositions, develop an application for hazardous non-recycle composition and develop mathematical models for the weight of the composition of e-waste. The study was based on data collected from e-waste collectors. The research project reveals the hazardous, non-hazardous and recycle, non-recycle composition in selected devices are; 1G mobile phones (0.5kg), 2G mobile phones (0.235kg), 3G mobile phones (0.155kg), 4G mobile phones (0.145kg), Tv (14kg), laptops (2.3kg), computers (9kg), A/C machines (34kg), refrigerators (135.5kg), fluorescent bulbs (0.185kg), and washing machines (34kg). Average weight has to be considered because of the different types, different models, different brands for the same device. Mercury is the only non-recycle hazardous composition in these devices. The results of this research revealed the ten compositions (mercury, plastic, copper, aluminum, cadmium, silver, gold, palladium, steel and lead) found in e-waste and how to calculate them.

The study reveals the amount of weight of compositions that can be found in e-waste and which compositions can be affected by the environment. The proper e-waste management system is needed to minimize e-waste generation. E-waste recycling is necessary but should conduct in a proper manner.

Keywords: e-waste, The weight of compositions, e-waste Management

Introduction

Electrical and Electronic waste or e-waste is discarded electrical and electronic devices such as mobile phones, sim cards, batteries, Air condition (A/C) machines, Washing machines, Fluorescent bulbs, Refrigerators, Computers, Laptops, etc (Samarakoon, 2015). With the rapid development of technology, e-waste has become an environmental and health concern in developing countries. Electrical and electronic devices demand is rising day by day due to the rapid development of technology. Because of that global e-waste growth is gradually increased day by day (Shibly and Thelijjagoda, 2018). The volume of e-waste generated in the past few 8 years in million metric tons as well as the world's worst e-waste offenders in 2018 (*Outlook on per capita e-waste generation globally 2018 | Statista*, no date). When e-waste is mishandled in terms of being discarded into open dumps or burn pits rather

than recycled, it creates a serious impact on the environment including groundwater, soil, air quality and the health of humans and animals since e-waste consist many types of hazardous heavy metals, acids, toxic chemicals, and non-degradable plastics (Sivaramanan, 2014). E-waste has been generated rapidly worldwide due to the high demand for electronic and electrical devices and the development of technology as well as the low recycling rate of e-waste (Samarakoon, 2015). Most of the e-waste has been generated due to poor recycling and disposal of electronic electrical devices. Because of that, e-waste becomes a major problem worldwide (Chan *et al.*, 2007). The rapid development of electrical and electronic industries and the continuous upgrading of a new version of electronic and electrical products lead to the discard more and more products of electrical and electronic, which produce large e-waste in the world (Osibanjo and Nnorom, 2007). Sri Lankan e-waste collectors are only doing dismantling the devices and send them to foreign countries like Japan, Belgium, India, and Spain. Other waste generated through the e-waste dismantling process includes glass materials sent to the glass manufacturing industry, metal materials to recycling in the steel manufacturing industry, plastic materials sent to the plastics recycling industry and non-recyclable materials are disposed of through cement kiln co-processing (Ranasinghe and Athapattu, 2020). Cement kiln co-processing means the use of waste as raw material, energy source, fossil fuel, etc (Baidya, Ghosh and Parlikar, 2016). This method is used because of the lack of facilities in Sri Lanka to recycle. Other than registered e-waste collectors, some companies like Abans, Singer and LG use the new method which is, if someone buys a new model of equipment they give a discount if they bring the old model or previous used one to them. Then they collect it and send them to either e-waste collectors or their head company. This method helps to prevent throwing those electrical and electronic devices to the open dump (Samarakoon, 2015). Basel Convention is the international treaty that was designed to reduce the movements of hazardous waste between the nation and prevent the transfer from developed to less developed countries (Frankshtein *et al.*, 1972). Electrical and electronic equipment mainly depends on the imported goods to Sri Lanka. Therefore a noticeable increase of e-waste generation can be seen in Sri Lanka in past few years (Ranasinghe and Athapattu, 2020).

Recently, lots of e-waste can be seen in the open yards. There is a possibility of leaching of heavy metals to the ground and surface water due to this open yard disposal of e-waste. Karadiyana and Gohagoda dumpsite show a higher concentration of compositions like Fe, As, Cu, Ni, Cd, Zn, Pb, and Mn (Ranasinghe and Athapattu, 2020). Sri Lanka is still far away from e-Waste management compare to other countries and still not identify all types of e-Waste generate in Sri Lanka (Samarakoon, 2015). Unfortunately, Sri Lanka has not improved in e-waste recycle and e-waste management (Ranasinghe and Athapattu, 2020). Therefore, the objectives of this research were to find out different types of e-waste generate in Sri Lanka, identify different compositions, develop an application for hazardous non-recycle composition and develop mathematical models for the weight of the composition of e-waste.

Methodology and Experimental Design

A. Methodology

The main objective of this research is to find out the weight composition of selective

electrical and electronic equipment and design a mathematical model for the weight content of compositions in selected equipment which are released to the environment through e-waste.

Two types of data collection techniques were used in this case study to collect data. They were;

(1) Interviews
(2) Documents and Records

Central Environment Authority was selected to study the current situation of e-waste management in Sri Lanka. Data collection was started with six selected e-waste collectors in a way of representative of the population who registered under Central Environment Authority. The formal interview methods were used to collect data from e-waste collectors. Secondary data collection was done by using e-waste collector's company database information and reports. The main objective of this case study is to find out the generated e-waste amount from annual imports electrical and electronic items in Sri Lanka. Because of study, the average weight content was selected for each device due to different types of models, brands for the same equipment. Composition weight content was taken for mg in 1kg of e-waste in the same device. For example; Gold weight content in 1kg of mobile phones.

B. Experimental Design

The case study finding reveals the different types of e-waste generated in Sri Lanka can be found as discarded 1G mobile phones, 2G mobile phones, 3G mobile phones, 4G mobile phones, washing machines, A/C machines, refrigerators, Tv, laptops, computers and fluorescent bulbs. These items have different types of brands names, model types for the same equipment. Therefore, the weight of equipment can be varied with the types and models because of this reason average weight need to be considered. Table 1. shows the average weight of this electrical and electronic equipment and the number of equipment in 1kg. Number of equipment in 1kg is needed to find the weight of compositions of equipment imported to Sri Lanka.

(Number of item in 1kg = 1/Average weight of equipment)

Table 12 Average Weight of the equipment and number of equipment in 1kg

Equipment (x)	Average Weight in kg	Number of items in 1kg
1G Mobile Phones	0.5	2
2G Mobile Phones	0.235	4.255
3G Mobile Phones	0.155	6.452
4G Mobile Phones	0.145	6.867
Washing Machines	90	0.011
A/C Machine	34	0.029
Refrigerators	135.5	0.007
Tv	14	0.071
Laptops	2.3	0.435
Computers	9	0.111
Fluorescent Bulb	0.185	5.405

From the above findings, identify the different types of compositions in the electrical and electronic equipment that can be affected to the environment because e-waste contains toxic materials. Aluminium, plastic, copper, mercury, lead, cadmium, silver, gold, palladium and steel were identified as compositions in the electrical and electronic equipment. Table 2. shows the types of compositions and the weight of compositions (mg/kg) in e-waste.

Table 13 Types of Compositions

Equipment (x)	Weight of the Compositions (mg/kg)									
	Aluminium	Plastic	Copper	Mercury	Lead	Cadmium	Silver	Gold	Palladium	Steel
Computers(x_1)	50	230	200			0.06		0.01		70
Refrigerators (x_2)	75	100	50							50
Washing Machines(x_3)	90	240	20	0.01		0.04				370
TVs(x_4)	100	280	50			0.06	0.01	0.05	0.001	
A/C Machines(x_5)	130	150	170			1.36				460
Laptops(x_6)	16.3	465.9	43.3		5.3		0.1			
1G Mobile Phones(x_7)	50000	28000	50000	7.5	45000	10000	1500	186.5	56.9	
2G Mobile Phones(x_8)	50000	20000	50000	8	45000	10000	1572.5	187	38.4	
3G Mobile Phones(x_9)	50000	25000	50000	10	45000	10000	1630	190.9	40.1	
4G Mobile Phones(x_{10})	53448.3	25000	65000	10	46724.4	10000	1680	250	41	
Fluorescent Bulbs(x_{11})	97297.3			50000						

Results

Starting from the above findings of the composition weight of electrical and electronic equipment, mathematical models were developed. Figure 1., Figure 2., Figure 3. and Figure 4. show the relationship between the weight of the compositions in mg/kg and the types of equipment.

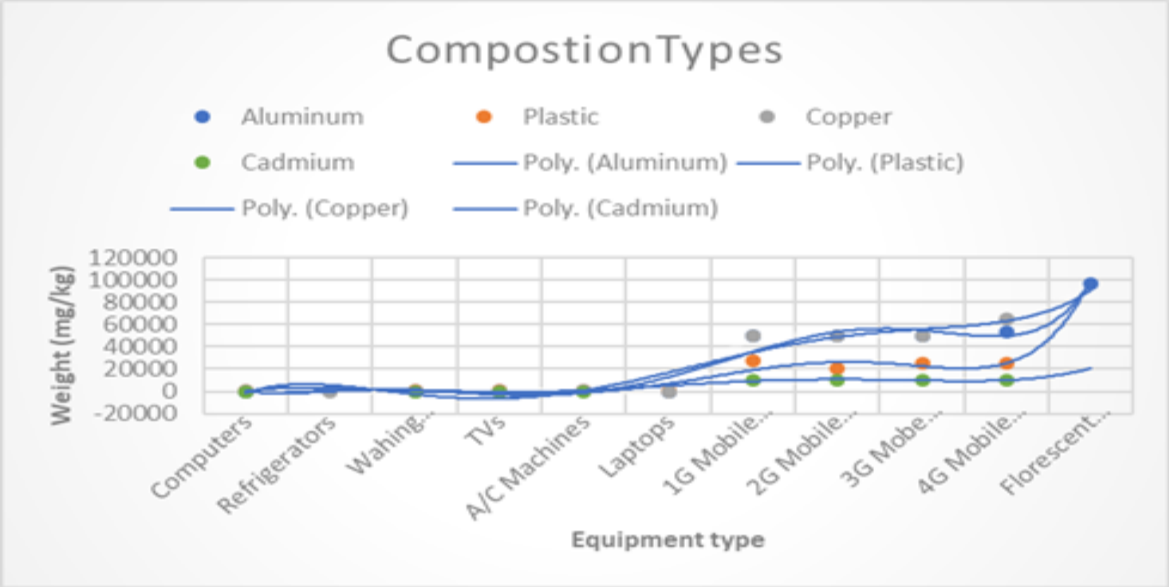

Figure 1 Aluminium, Plastic, Copper and Cadmium weight of selected electrical and electronic equipment

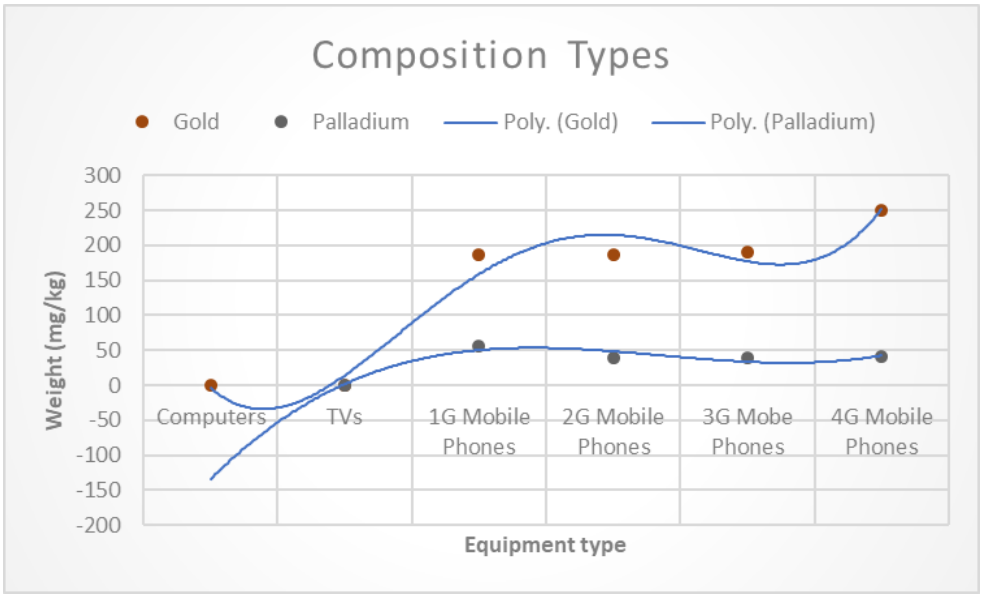

Figure 2 Gold and Palladium weight of selected electrical and electronic equipment

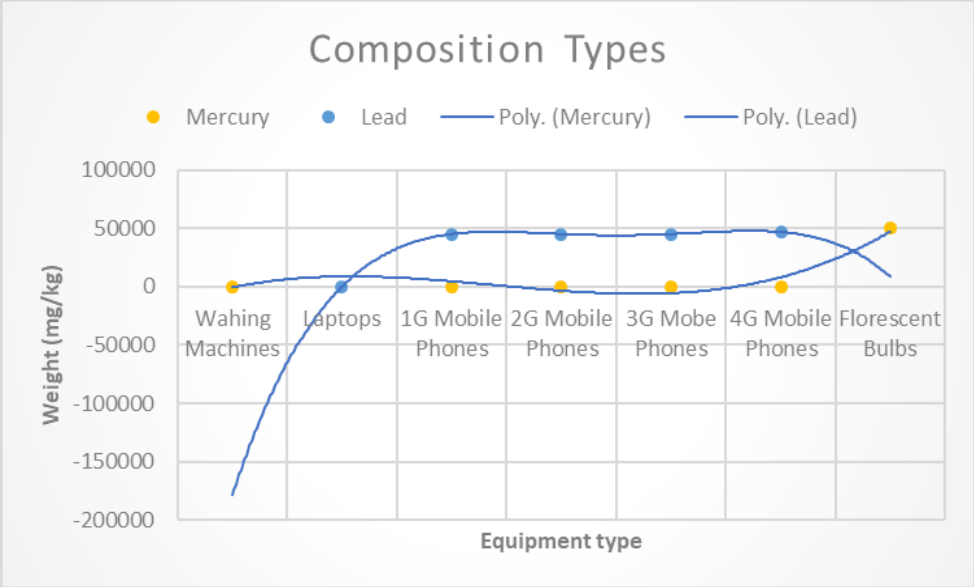

Figure 3 Mercury and Lead weight of selected electrical and electronic equipment

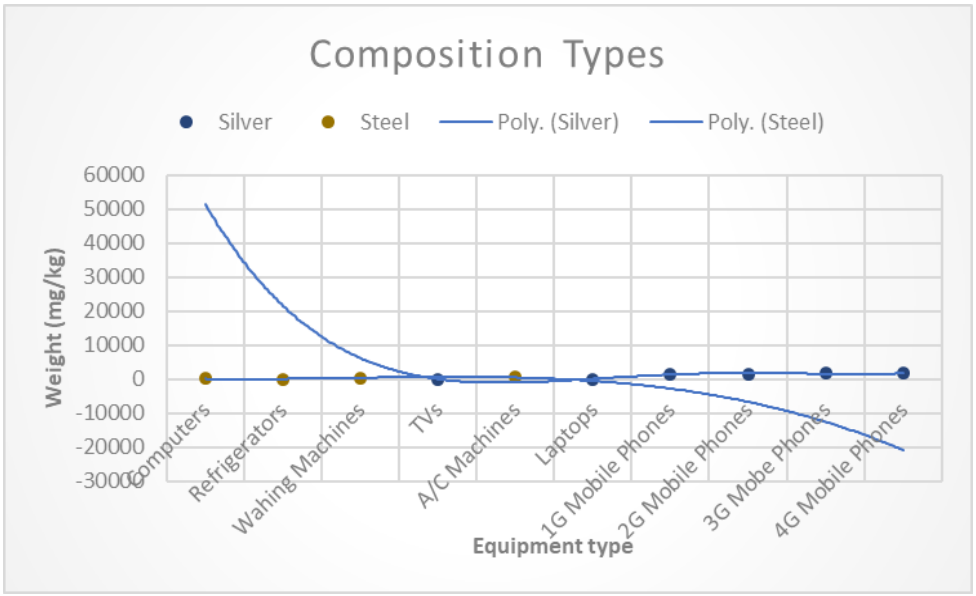

Figure 4 Silver and Steel weight of selected electrical and electronic equipment

$$y_{aluminum} = 12.575x^6 - 401.31x^5 + 4807.5x^4 -$$

Quadratic regression equations were used to develop the mathematical models to calculate the composition weight of the selected device that imported to Sri Lanka and the matrices were used to calculate the weight of the composition in the e-waste which generates from the total selected electrical and electronic equipment imported to Sri Lanka.

A. Weight Composition of Aluminium

(1)

$$\text{Weight of Aluminium} = y_{\text{aluminum}} \times \text{Weight of the equipment} \quad (2)$$

Total Aluminum Weight =

$$\begin{bmatrix} 0.999x_1 \\ 0.949x_2 \\ 0.99x_3 \\ 0.994x_4 \\ 0.986x_5 \\ 1.001x_6 \\ x_7 \\ x_8 \\ x_9 \\ 0.996x_{10} \\ x_{11} \end{bmatrix} \begin{bmatrix} 50 & 75 & 90 & 100 & 130 & 164.3 & 50000 & 50000 & 50000 & 53448.3 & 97297.3 \end{bmatrix}$$

(3)

B. Weight Composition of Plastic

$$y_{plastic} = 12.182x^6 - 393.97x^5 + 4875.4x^4 - 28956x^3 + 8[illegible]$$

(4)

Weight of Plastic = $y_{plastic}$ ×
Weight of the equipment × no. of Equipment

(5)

Total Plastic Weight =

$$\begin{bmatrix} 0.949x_1 \\ 0.986x_2 \\ 0.999x_3 \\ 0.99x_4 \\ 0.994x_5 \\ 1.001x_6 \\ x_7 \\ x_8 \\ 0.996x_9 \\ x_{10} \end{bmatrix} \begin{bmatrix} 100 & 150 & 230 & 240 & 280 & 465.9 & 20000 & 25000 & 25000 & [illegible] \end{bmatrix}$$

(6)

C. Weight Composition of Copper

$$y_{copper} = 37.188x^5 - 1113.7x^4 + 12045x^3 - 55517x^2 + [illegible]$$

(7)

Weight of Copper = y_{copper} ×
Weight of equipment × No. of equipment

(8)

Total Copper Weight =

$$\begin{pmatrix} 0.99x_1 \\ 1.001x_2 \\ 0.949x_3 \\ 0.994x_4 \\ 0.986x_5 \\ 0.999x_6 \\ x_7 \\ x_8 \\ x_9 \\ 0.996x_{10} \end{pmatrix} \begin{bmatrix} 20 & 43.3 & 50 & 50 & 170 & 200 & 50000 & 50000 & 50000 & 65000 \end{bmatrix}$$

... (9)

D. Weight Composition of Cadmium

$$y_{cadmium} = 51.276x^5 - 1153.7x^4 + 9369.2x^3 - 33036x^2 + 49706x - 24995$$

(10)

Weight of Cadmium = $y_{cadmium}$ ×
Weight of the equipment × No. of Equipment

.(11)

Total Cadmium Weight =

$$\begin{bmatrix} 0.99x_1 \\ 0.994x_2 \\ 0.999x_3 \\ 0.986x_4 \\ x_5 \\ x_6 \\ x_7 \\ 0.996x_8 \end{bmatrix} \begin{bmatrix} 0.04 & 0.06 & 0.06 & 1.36 & 10000 & 10000 & 10000 & 10000 \end{bmatrix}$$

(12)

E. Weight Composition of Gold

$$y_{gold} = 8.8367x^4 - 124.53x^3 + 590.32x^2 - 1015.1x + 537.73$$

(13)

Weight of Gold = y_{gold} ×
Weight of the equipment × No. of Equipment

(14)

Total Gold Weight =

$$\begin{bmatrix} 0.999x_1 \\ 0.994x_2 \\ x_3 \\ x_4 \\ x_5 \\ 0.996x_6 \end{bmatrix} [0.01 \quad 0.05 \quad 186.5 \quad 187 \quad 190.9 \quad 250]$$

(15)

F. Weight Composition of Palladium

$$y_{palladium} = 4.3083x^3 - 42.046x^2 + 132.94x - 94.917$$

(16)

Weight of Palladium = $y_{palladium}$ ×
Weight of the equipment × No. of equipment

(17)

Total Palladium Weight =

$$\begin{bmatrix} 0.994x_1 \\ x_2 \\ x_3 \\ 0.996x_4 \\ x_5 \end{bmatrix} [0.001 \quad 38.4 \quad 40.1 \quad 41 \quad 56.9]$$

(18)

G. Weight Composition of Mercury

$$y_{mercury} = 1041.3x^4 - 12264x^3 + 49631x^2 - 79848x + 41638$$

(19)

Weight of Mercury = $y_{mercury}$ ×
Weight of the equipment × No. of equipment

(20)

Total Mercury Weight =

$$\begin{bmatrix} 0.99x_1 \\ x_2 \\ x_3 \\ x_4 \\ 0.996x_5 \\ x_6 \end{bmatrix} [0.01 \quad 7.5 \quad 8 \quad 10 \quad 10 \quad 50000]$$

(21)

H. Weight Composition of Lead

$$y_{lead} = 3893.3x^3 - 41221x^2 + 138314x - 100363$$

(22)

Weight of Lead = y_{lead} ×
Weight of the equipment × No. of equipment

(23)

Total Lead Weight =

$$\begin{bmatrix} 1.001x_1 \\ x_2 \\ x_3 \\ x_4 \\ 0.996x_5 \end{bmatrix} [5.3 \quad 45000 \quad 45000 \quad 45000 \quad 46724.4]$$

(24)

I. Weight Composition of Silver

$$y_{silver} = 61.14x^4 - 886.51x^3 + 4301.1x^2 - 7478x + 3979.5$$

(25)

Weight of Silver = y_{silver} ×
Weight of the equipment × No. of Equipment

(26)

Total Silver Weight =

$$\begin{bmatrix} 0.994x_1 \\ 1.001x_2 \\ x_3 \\ x_4 \\ x_5 \\ 0.996x_6 \end{bmatrix} [0.01 \quad 0.1 \quad 1500 \quad 1572.5 \quad 1630 \quad 1680]$$

(27)

J. Weight Composition of Steel

$$y_{steel} = -81.667x^3 + 630x^2 - 1298.3x + 800$$

(28)

Weight of Steel = y_{steel} ×
Weight of the equipment × No. of equipment

(29)

Total Steel Weight =

$$\begin{bmatrix} 0.949x_1 \\ 0.999x_2 \\ 0.99x_3 \\ 0.986x_4 \end{bmatrix} \begin{bmatrix} 50 & 70 & 370 & 460 \end{bmatrix} \quad (30)$$

Compositions were categorized under hazardous, non-hazardous and recycle non-recycle after finishing mathematical models for compositions. Table 3 shows the categorization of compositions.

In consonance with the table 3., Mercury is the only hazardous non-recycle composition found in the above-selected devices. Therefore, application was developed to find the weight of mercury in the e-waste of the selected device. This application was developed by using Visual basic software.

Figure 5 shows the application of Mercury Analyzer.

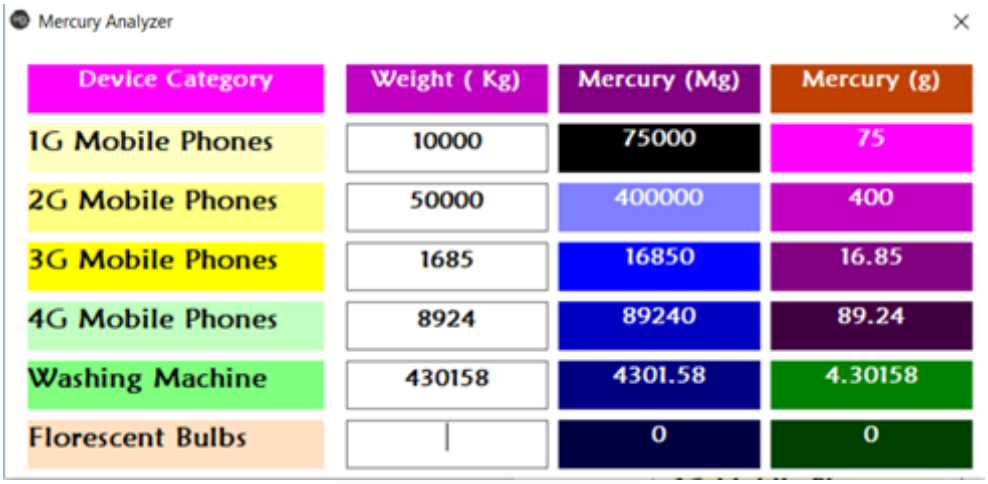

Figure 5 Mercury Analyzer

Table 14 Composition categorize under hazardous, non-hazardous, recycle and non-recycle

Device	Hazardous		Non-Hazardous	
	Recycle	Non-Recycle	Recycle	Non-Recycle
1G Mobile Phones	Silver Lead Cadmium Palladium	Mercury	Plastic Aluminium Copper Gold	
2G Mobile Phones	Silver Lead Cadmium Palladium	Mercury	Plastic Aluminium Gold Copper	
3G Mobile Phones	Silver Lead Cadmium Palladium	Mercury	Plastic Aluminium Gold Copper	
4G Mobile Phones	Silver Lead Cadmium Palladium	Mercury	Plastic Aluminium Gold Copper	
TVs	Silver Cadmium Palladium		Plastic Aluminium Gold Copper	
Laptops	Silver Lead Ferrous		Plastic Aluminium Copper	
Computers	Cadmium Antimony		Plastic Steel Copper Aluminium Gold Glass	
Florescent Bulbs	Iron	Mercury	Silicon Aluminium	
A/C Machines	Cadmium		Plastic Steel PCB Aluminium Copper	
Washing Machines	Cadmium	Mercury	Plastic Steel Aluminium Copper	
Refrigerators	Polyurethane		Plastic Steel Stainless Steel Glass Aluminium Copper	

Disscussion

There are many ways of e-waste generate in Sri Lanka. This research project is only focused on the main e-waste to generate methods in Sri Lanka. Most of e-waste contains different types of compositions and out of the aluminium, plastic, cadmium, mercury, steel, silver, lead, gold, palladium and copper were selected for this case study. Most of the e-waste contains toxic materials that effect to the environment, surface water and groundwater. Some compositions can be found as hazardous and non-hazardous and can be recycled and cannot be recycled. This

research study shows the amount of weight of identified composition, that can be released to the environment within a period from the e-waste. Generally, the high amount of electrical and electronic equipment ae imported to Sri Lanka due to the use of modern technology. Therefore, it is important to have a general idea about the weight of compositions released from this equipment. Another aspect of this research is to find the amount of weight that releases to the environment by using the number of imported equipment within a known period. The number of items in 1kg of selected equipment should be substituted to find the "y" in the graphs shown in figure 1, figure 2 and figure 3. There are different types of models, brands in the electrical and electronic equipment in the present market. Therefore, the weight of the equipment may vary with the model, type and brand. This case study is used the average weight of all electrical and electronic equipment to overcome this problem. Average weight and number of items that imported to Sri Lanka with a period are used to calculate the weight of the composition. Matrix model was developed to identify the total composition weight from the all selected electrical and electronic equipment. This model helps to calculate composition weight that can affect to the environment from the e-waste. This gives an idea about the amount of weight of composition that releases to the environment from the e-waste. Mercury is the most harmful composition found in this research. Therefore, application was developed to identify the weight of mercury in selected equipment load.

Current practices of e-waste management are the collection, dismantling, reuse, recovery, and disposal. Green computing is used to minimize e-waste which is designing, constructing, running a computer system to be energy-efficient. Mainly refer to promote recyclable or biodegradability of products to reduce the use of hazardous material. Energy-saving electrical and electronic equipment should be introduced to minimize e-waste generation. Best practices of e-waste minimization are used as a 3-R concept which is Reduce, Reuse and Recycle. Reduce can be done by buying a new one if the end of the life of equipment only. Otherwise, try to repair it and use it. Same for the reuse also. Recycle can be done to recyclable materials, for example, glass parts to the glass manufacturing industry to recycle. Steel materials to steel manufacturing industries etc. Energy consumption methods can be used to minimize e-waste. Sustainable develop methods can be introduced to minimize e-waste.

Conclusion

Sri Lanka is still behind in e-waste management sector because it has not been identified all the types of e-waste in Sri Lanka. Therefore, proper e-waste management have not developed in Sri Lanka. Major types of e-waste generation devices in Sri Lanka can be identified as discarded personal computers, 1G mobile phones, 2G mobile phones, 3G mobile phones, 4G mobile phones, TV, laptops, A/C machines, refrigerators, fluorescent bulbs, and washing machines.

There are many types of compositions that can be identified in electrical and electronic devices. Major compositions can be identified as aluminium, mercury, plastic, copper, lead, cadmium, silver, gold, palladium, and steel. These identified compositions can be classified as Hazardous and Non-hazardous, Recycle and Non-recycle compositions. From this classification, mercury is the only non-recycle and hazardous composition identified from all these compositions. Developed application can be used to find out the weight

of mercury inside the identified e-waste in any weight of kg.

The developed mathematical models in this research can be used to identify weight composition of selected electrical and electronic device and can be calculated weight compositions of e-waste generate in Sri Lanka from the annual imports of electrical and electronic equipment.

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Evaluating the Efficiency of a Traffic Signal Light over a Traffic Policeman

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Abstract: The overall effect of traffic is considered to be high, at most of the intersections when they are controlled by traffic signal lights during peak hours

. This causes lengthy queues and user inconveniences at intersections. Traffic police officers also control some of the intersections during peak hours in order to reduce this queue length and waiting time. The objectives of this research were to determine the relationship between the queue length formed and vehicular delay at peak hours, when the intersection is controlled by traffic signal lights and traffic policemen. Data was collected in two four-way intersections at Kanatta road / Dudley Senanayake Mawatha and Golumadama intersection. When the queue length was considered by 5-minute time intervals, the number of vehicles in the queue were higher with traffic signal control, compared to police controlled intersection. Further, per signal cycle queues were also counted in the said two scenarios. The observed values were furthers tested using Contingency Table analysis (Chi-square test) to assess whether the effect is statistically significance. Results showed that, queue lengths and the number of waiting hours were higher when the intersection was controlled by traffic signal lights compared to a traffic policeman. However, per cycle waiting time was significantly higher when controlled by policemen. Therefore, when a single-user point of view, the intersection delay may seem higher when controlled by a traffic policeman. However, the overall delay at the intersection is lesser with the police control.

Keywords: Traffic Signal Lights, Traffic Policeman, Intersection delay

Introduction

The invention of motor vehicle had a great impact on human lives. This lead to the development and improvement of road conditions, with increased speeds and capacities which resulted vulnerability for the road users. So the necessity of properly controlling and channelization of traffic is a significant factor for road user safety.

In the early days, human resources were used to control traffic. In 1722, the Lord Mayor had appointed three men to control traffic on the London bridge, whom considered as the world's first traffic police. The first traffic signal had been installed in 1868 in London. It has used a semaphore 'arms' together with green and red gas lamps. In 1925, first three colored traffic signal light has been installed in New York. The first ever traffic signal light in Sri Lanka has been installed at Naval and Maritime Academy in Trincomalee. Traffic signal lights are used throughout the world to reduce conflicts by time-sharing right of way (Allsop, 1971; Gerlough and Wagner, 1964; Ndoke, 2006).

Traffic lights show the correct way to the road users by illuminating lamps or Light-Emitting Diods (LEDs) of standard colours: red, amber, and green, following the universal colour codes in the typical sequence of colour phases as mentioned (Reilly, 1997).

1) The green light allows traffic to proceed in the direction denoted, if it is safe to do so, and there is room on the other side of the intersection.
2) The amber light warns that the signal is about to change to red.
3) A flashing amber indication is a warning signal.
4) The red signal prohibits any traffic from proceeding.
5) A flashing red indication is treated as a stop sign.

Presently, road users face complications at intersections due to longer queue lengths and waiting times when the intersection is controlled by traffic signal lights. In order to reduce this complication, traffic policemen are used to control traffic at intersections during peak hours. The reason was believed as the signal cycle timings could not be optimized to a better scenario to cater for the high traffic flow rates. This research has evaluated how efficient the replacement of traffic signal lights could get by traffic policemen.

A study in the similar field was carried out by Parr et.al (2016) with the objective of quantifying the effect of manual traffic control at an intersection operation and to develop a quantitative model to describe the decision-making of police officers giving way for special events and emergencies (Parr et al., 2016). Apart from the main objective, the study has had three more objectives of conducting a quantitative analysis of the stimulus-response relationship between the traffic stream and officers' right-of-way decisions while directing traffic, simulating manual traffic control for the intersections in the study and evaluating the cost-benefit relationship between manual traffic control and automated traffic control. Results from that study has suggested that manual traffic control increased the intersection throughput by 16 percent because of a decrease in lost-time associated with longer phase lengths.

Methodology

This research was initially conducted focusing two factors;

1) The total number of vehicles at the queue formed in red traffic signal light
2) The total waiting time of vehicles at red traffic signal light

A. Site Selection

The Galle Road and Baseline Road have a number of intersections that are highly congested most of the time. This is due to the high volumes of vehicles that are approaching and leaving Colombo and a variety of trip attractionsare located around this area. Further, most of the intersections are highly congested during the school and office starting and ending times as well.

Various types of intersections around the area were identified as, T-intersections, Y-intersections, four-way intersections, five-way intersections, roundabouts, intersections with separate right turns, intersections without separate right turns, intersections with and without count down timers etc. Accordingly, this research focussed on two four-way intersections (Kanatta RD/ Dudley Senanayake Mw and Golumadama junction) which were controlled by both traffic police and traffic signal lights time to time. These intersections are shown in Figure 1.

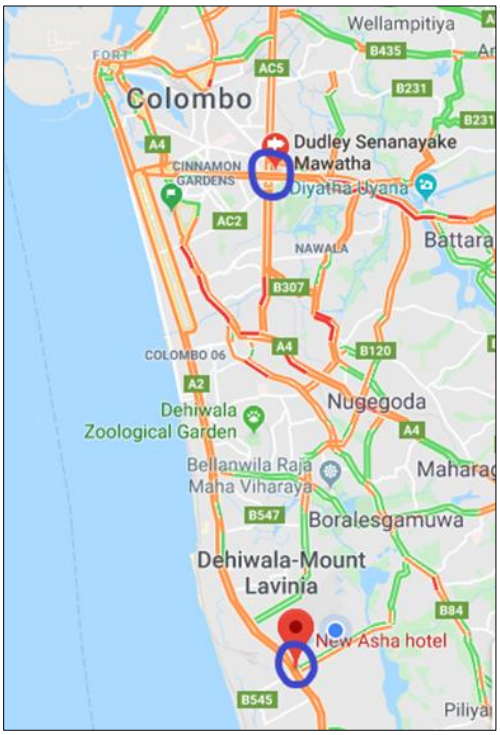

Figure 10. Selected Intersections
Source: Retrived from Google Maps (2019)

B. *Data Collection Duration*

Data was collected on two weekdays; Monday and Thursday. The peak hours differed with the day and Monday morning peak was not considered when taking the counts to capture the commuting traffic. This was because, it differed from a normal day, since higher number of vehicles travelled through selected intersections on Monday morning peak hours as returning pupoulation who were away during the weekends. Google maps were used to find the peak hour details of the selected intersections which is deliberated in Table 1. The traffic overlays in Google Maps were used on street maps. By the color indications of it, traffic congestions and mild traffic so forth were identified. By adjusting the day of the week and time of the day, behavior of a typical traffic flow on the selected intersections were realized. By adjusting the time periods, the time period which has the most congested condition for a given intersection was recognized as the peak period.

Table 15. Peak Hours Selection

Intersection	**Morning peak hour**	**Evening peak hour**
Golumadama	0730hrs-0830hrs	1550hrs-1650hrs
Kanatta RD/ Dudley Senanayake Mw	0840hrs-0940hrs	1635hrs-1735hrs

C. *Queue length determination*

The data collection was conducted in three types of approaches which are mentioned as follow;

1) Field Surveys
2) Manual Data Collection
3) Video Surveys

After the data collection process, the data analysing was carried out to evaluate how efficient was the replacement of traffic signal lights by traffic policemen could be.

According to the traffic control techniques, the types of traffic controls that were selected for this research was the controlling by the traffic police officer and the control of traffic by the traffic signal lights. Initially, signal light phases were observed in order to identify the phase at which the intersection was controlled by traffic signal lights and the phase of which it was controlled by traffic policeman. During the field survey, parameters such as queue lengths and the vehicular delays were observed and subsequently, the data was used for the evaluations.

Traffic counts were obtained with the use of tally counters and a mobile software called “Counter”, which made the collection and recording of data convinient with limited

human resources available. The manual counts were taken with the assist of sixteen observers. Five observers for each main road and three observers for each by road was considered.

Subsequently, five observers were allocated for the main road such that large busses/trucks/SUVs, threewheels/cars, van/minitrucks/motorcycles were counted by each individual respectively and one individual counting the right turnings and others taking the left turnings. Three members in the byroads, took the counts as number of left turns and right turns with the use of the mentioned mobile application.

During the data analysis stage, Passenger Car Unit (PCU) values were taken into consideration which were from a previous study conducted by the University of Moratuwa in 2016 (Jayaratne et al., 2016). The values considered for the analysis could be mentioned as;

1)	Car	1.0	
2)	Three-wheeler	0.6	
3)	Van/mini truck		1.2
4)	Motor cycle	0.2	
5)	Large bus	4.1	
6)	SUV	1.4	
7)	Truck	3.2	

D. Video Surveys

During this study, the traffic counts at Kanatta road/ Dudley Senanayake Mw (Borella junction) were taken using video recordings. The necessary permissions were taken from the Borella police station for the video recording since it was conducted at a public place. Two wide-angle cameras were fixed on either side of the road such that, it covered all four roads at the intersection at the same time. Moreover, four other cameras were fixed to take the queue lengths of each approach.

Video surveys were conducted at morning and evening peak hours when the intersection was controlled both by, traffic signal lights and by traffic police officers. The respective queue lengths were recorded separately for the calculation of the existing signal phasing arrangement at the intersection. Video recording was done at peak hours for a total time duration of one hour. Also separate queues that were generated when the approach was stopped by the traffic controls were recorded at the same time in order to compare the queues generated when intersection was controlled by the traffic police officer and when controlled by traffic signal lights.

Data extraction and analysis was done by counting the vehicles from the videos taken and accordingly, data was tabulated considering the two approaches. This data analysis was useful in order to find the queue length formed when the approached vehicle was stopped by traffic signal lights or policemen. The number of vehicles in the queues which were at the start of red signal light were tabulated with five-minute intervals.

E. Data Analysis

Contingency table analysis or the Chi-square test was done to analyze statistical significance of any effect between the two traffic control types.

H_0: Null hypothese: Two queue lengths are independents of the traffic control type

H1: Alternative hypothesis: H_0 is not true,

If the Chi-square $(\chi^2)_{\text{critical}} < \chi^2_{\text{estimated}}$; H_0 is rejected

If the Chi-square $(\chi^2)_{\text{critical}} > \chi^2_{\text{estimated}}$: No sufficient evidence to reject H_0

Using this statistical test, it was tested whether the observed increase in queue length or decrease, is actually a statistically significant difference. Confident interval was taken as 95% for all analyses.

Also Signal timing calculations were done in order to see whether the traffic signal lights were operating at correct phasing arrangement. Webster's method was used in that.

Results and Discussion

A. Que Lengths formed at Borella Junction

The results presented in Figure 2 shows a clear difference between the queue lengths formed with the two control methods. However, this was not found statistically significant.

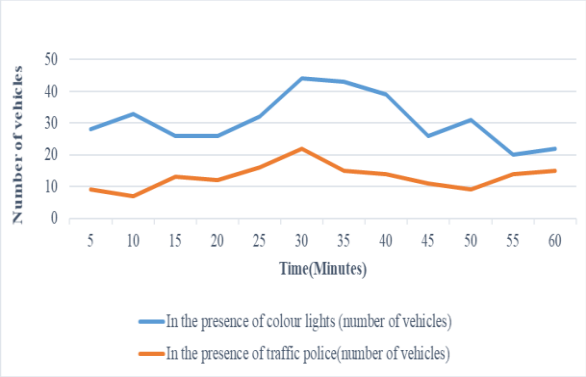

Figure 11. Queue lengths towards Baseline

Results showed that a higher volume of vehicles waited at the approach towards baseline, when the intersection was controlled by traffic signal lights. Accordingly, similar behaviour of higher volume of vehicles controlled by traffic signal lights were observed from the results towards Kollupitiya, towards Dudley Senanayake Mawatha and towards Dehiwala at the Borella junction.

B. Vehicle Waiting Times at Borella Intersection

As shown in Table 2, a comparison between the delay at each approach and the total delay caused at the intersection when the intersection was controlled by traffic signal lights and traffic policemen was carried out. Same as previous, the approach the taken as towards Baseline as shown in table 3, and the other three approaches; approach towards Dudley Senanayake Mawatha, Borella and Kollupitiya. The results further proved that, all four approaches showed a higher queue length when the intersection was controlled by traffic signal lights.

Table 2. Results of Queue Length Towards Baseline at Borella Junction

Type of control	Vehicle hours				
	Towards Kollupitiya	Towards Baseline	Towards Dudley Senanayake Mawatha	Towards Borella	Total Delay
Traffic Police	12.62	4.30	3.53	3.61	24.06
Traffic Signal Lights	21.07	10.59	12.41	12.81	56.88

C. Contingency table analysis

When the five-minute interval queue lengths (converted to PCU) were considered, the Table 3 was obtained.

Table 3. Comparison of queue length: 5 min intervals

	Approach_1	Approach_2	Approach_3	Approach_4
SL	85.67	30.83	35.58	36.67
PM	27.17	13.08	7.58	11.83

Where,

SL: With traffic signal light
PM: with traffic policeman
Approach_1: towards Kollupitiya
Approach_2: towards Baseline
Approach_3: towards Dudley Senayake Mawatha
Approach_4: towards Borella

$\chi^2_{critical}$ = 7.815 (for Confidence Interval of 95%)

$\chi^2_{estimated}$ = 1.5656 (Decimal placed were removed by rounding up for discrete variable definition)

7.815 > 1.5656

Therefore, no clear conclusion can be reached, and the null hypothesis is sustained. Moreover, the p-value is estimated .667225. Hence, the result is not significant at p < .05.

By observing the values, it seems that the queue length is longer when the intersection is controlled by a traffic signal light. However, that is statisticaly proven to be significant.

When the cycle-wise queue length is considered, the Table 4 can be developed

Table 4. Comparison of queue length: per cycle

	Approach_1	Approach_2	Approach_3	Approach_4
SL	73	103	104	105
PM	188	94	1391	95

$\chi^2_{critical}$ = 38.3877 (for Confidence Interval of 95%)

$\chi^2_{estimated}$ = 7.815 (Decimal placed were removed by rounding up for discrete variable definition)

38.7777>> 7.815

Therefore, the Null hypothesis is rejected. Hence, the visible increase in queue length can be considered statistically significant. Furthermore, the p-value is < 0.00001. The result is significant at p < .05.

D. Evaluating the Appropriateness of Current Phase at Golumadama Intersection

Currently, the Golumadama intersection is controlled with a five-phase signal light scheme. With the phase calculations done according to the 'Webster method', it was identified that the allocated phase scheme was not suitable to control the current traffic during peak hours at Golumadama Intersection. The results from the Webster's method showed that none of the phases satisfied the required condition. Due to lengthier calculations, it was not mentioned in this paper. So, as a result of the current allocated phase scheme, the vehicles had to face a greater delay at the intersection. However, as a soulution for this issue, a signal timing optimization could be implemented inorder to increase the intersection delay at that the intersection. Authors cannot comment on that without a traffic simulation software.

Conclusion

Use of a traffic policeman for traffic control at intersections of arterial vs collector or arterial vs arterial is frequently observed during peak periods. In Sri Lanka, this is observed at certain intersections where the right turns are high. However, as it is not observed in many other countries, traffic policemen are used in Sri Lankaa at signalized intersections with

amber light on for all movements. The reason for this is that the signal timing in the cycle does not help at high traffic flows in the peak hour (Alexander et al., 2014). As adaptive traffic signals are not availbe in Sri Lanka at the moment, traffic policemen are used in peak times to eliminate this issue. However, it is a social opinion that the delay at an intersection increases when it is controlled by a traffic policeman. This study attempted to study this scenario and conclude upon the suitability of the use of policemen at intersections. Contingency analyses were carried out for difference scenarios. Only some scnearios of this study are reported in this paper.

From the results obtained, it was observed that the queue lengths and waiting time for all approaches were high when the traffic was controlled by traffic signal lights compared with the control of traffic policemen. However, when the intersection was controlled by traffic police, the individual delay was greater, so a rider has to spend more time before clearing the intersection, if the queue in the clearing approach is greater.

The intersection delay showed that the delay observed while policemen controlled intersections were 32 vehicle hours lesser when compared with traffic signal lights. During this study, it was identified that a police officer would be good at allocating time properly, at any given situation, where he could give priority to emergency vehicles and he is able to use the common sense judgments on situations where necessary. Also, in overly saturated conditions, traffic policemen tend to run very long phases (longer time duration for one phase) in order to clear the whole queue resulting in unbalanced delays on other approaches. During the study, it was clear that the communication between the traffic policemen at neighboring intersections helped them for a better understanding of the queue situation of different approaches and giving them the priority as needed.

When the intersection was controlled by traffic policemen, the clearing shall be done in one approach at a time. One of the negative issues identified during this research was when the traffic police officer clear the approach, subsequently the sequence they use to clear the approach adversely affects the other approaches, resulting of a gradual vehicle block.

When considering the calculations done regarding the Golumadama intersection it was understood that the current phasing scheme was not suitable for that particular intersection during peak hours. With this phasing scheme all the vehicles which approached towards the intersection were not able to pass the intersection during green time causing long queue lengths. So, it is recommended that the traffic planners should consider alternative options to reduce the traffic at this intersection either by changing the phasing scheme or replacing a traffic policeman. Since this intersection is already controlled with a five-phase traffic scheme during peak hours, increasing of phases will rise the intersection delay. So that option would not be suitable to control the traffic, instead it is recommended to replace of signal lights with a traffic policeman during peak hours to control the traffic without causing long queues or traffic congestion at the intersection.

Therefore, when a single-user point of view, the intersection delay may seems higher when controlled by a traffic policeman. However, the overall delay at the intersection is lesser under that condition.

Therefore, with the results of this study, it can be seen that the first option to minimize the delay at intersections may not be to replace by

a traffic policeman at all the times. It can be checked whether a signal time optimization can be introduced. As a social study, it has to studied whether a road user prefers the individual waiting time to be lesser over minimizing the intersection delay.

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Waste Minimization for Small Airlines by Using Safety Management System Concepts

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Abstract: The detrimental effect of the aviation industry comes with its environmental damage, which has inevitably yet significantly increased over the years. Much research is conducted on demoting the environmental damage caused through air pollution, sound pollution, waste pollution, and hydrological pollution. This research aims to focus on developing a system that may reduce and moderate the waste production by the prevention of waste production, which can be done by amplifying a waste management system using scientific methodology and the minimization of waste production through waste type formation reduction. The concepts of safety management due to its inherent qualities of a comprehensive system Top to the bottom management system, a total study of safety in all aspects, has the ability to continuously improve. Furthermore, the organizational commitment from the top management to the bottom is substantial. As in the rest of the world, the aviation industry of Sri Lanka is also mounting at a rapid speed. This research was conducted as a case study of a small aviation industry organization. However, the waste management process of the Sri Lankan aviation organizations has not been given proper consideration to mitigate or prevent the immense waste production. In numerous research studies that have been conducted, the method for managing certain types of waste produced by aviation organizations was discussed. Henceforth, further research developed a waste management system that includes four annexes that can be used for the prevention and minimization of all types of waste produced by the aviation organizations in Sri Lanka.

Keywords: Waste, Safety, Environment, Hazardous Aviation, Management.

Introduction

A. Situation Awareness

1) Globale state: As, the world's demand of aviation services is rapidly growing and the technology of management of resources is in great importance to create cost effective ways to maintain the high quality and safety of air transportation. This paper is orientated towards big markets, particularly to aircraft maintenance service suppliers. These service providers have to act flexibly and efficiently to meet the customer demands. Through the operation of manufacturing and maintaining aircraft for the demand on aviation, potentially large environmental impacts of aviation industry (particularly, airports in terms of air quality, noise, and handling of solid hazardous solid wastes) need to be addressed by developing more sustainable environmental practices followed by its management, and safe disposal. Be it from managing infections due to the ever-growing burden disposed solid waste, exposure to hazardous materials, noise etc. Technical progress and new developments in aviation industry often go hand in hand with the developments in new environmental and

waste recycling technologies for maintaining hygiene and protection of the ambiance both on the ground and in air. As more and more waste related legislation is passed with stringent measures, airports and airlines are struggling to modernize their obsolete waste management systems and recovery procedures. Over the past three years, the progress and space of transformation in international aviation environmental protection, has been unprecedented, driven by key decisions from International Civil Aviation Organization member states, technology progress and societal expectations. Consequently, in this study, we will be comparing the environmental trends in the Sri Lankan aviation industry through the comparison and association of each aviation organization state in Sri Lanka. Thus, Safety Management System concepts are created in a way to emphasize more on "what to do" rather than "how to do it". The reason behind this is to create standards which are set in a way that accommodates a wide variety of types and sizes of organizations. These standards are designed to allow the 3 operators and service providers to integrate the safety management practices into their individual operational models. The absence of harmonized and standardized requirements in the beginning of Safety Management System implementation, the specific needs of the different types of operators/service providers as well as the differences in the existing service provision and business frameworks have set the pattern for the development of sector specific safety management systems. Further research is to comply Safety Management System concepts for an effective waste management through analyzing effectiveness.

Srilankan aviation industry can be dived in to two major components as international and domestic aviation. Srilankan airlines is the only organization in Sri lanka involve in international aviation and the waste is produce through its major operation area of maintenance organization passenger and cargo operations and airport stakeholders like cafeteria and other sources.

In domestic aviation as there are only a very few schedule air transportations. So, the main type of aviation operations is for training and site seeing tours. Due to this reason the only considerable amount waste is generated in maintenance of aircraft.

Critical negative impacts of improper waste management are;

- Open dumping can contaminate water sources
- Contaminate food supply and cause food borne disease
- It can create fire accident
- Slum areas
- It can create nuisance: bad odor, smoke, dust aesthetical problem discomfort: sneezing, coughing

Advantages of optimizing waste management to aviation are;

- Savings in disposal costs
- More economical processes through the recycling and reuse of materials
- Reduction in short-term environmental costs through better process control
- Reduction in potentially large liabilities in the long term
- Reassessment of processes, which may make them more efficient

2) Research questions:

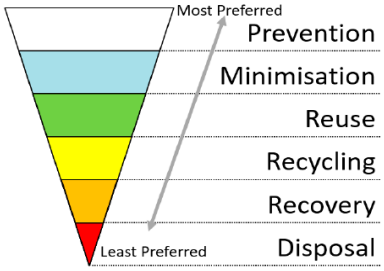
1. What are effects and complications of waste management in the aviation industry of Sri Lanka?

2. Can scientific methodology be use for waste fabrication minimization?

2) Focal points of the Research:

1. Waste management study on the effectiveness of waste management systems in Copenhagen and Kansai International Airports.
2. Waste management study on United Kingdom airports giving the affect of waste on environment
3. Problems of aviation waste management as a globally researched area of emphasis
4. Waste management in Sri Lankan aviation, which seems to be limited to research conducted on solid waste management alone.
5. Scientific methodology which have failed to consider a comprehensive waste management in aviation organization.

3) Objectives of research: The method of waste management in the world



The implementation of waste management systems to achieve the most preferred method of administration.

- Prevention of waste production

The implementation of Waste type formation reduction systems, by taking the amount of waste produce by organization, into consideration.

- Minimization of waste production

Literature Reviews

1) Global waste management: Waste management is the one thing, which just about every government must provide for its resident(Zhu *et al.*, 2008).

At a Glance:

- In solid waste management there is no throwing 'away'.
- The organic fraction of waste, collection vehicles, and waste disposal methods contribute to Green House Gas emissions.
- The last two decades have brought a new challenge for waste management: the growing vagaries of global secondary materials markets(Zhu *et al.*, 2008)

In solid waste management, there is no 'away'. When 'throwing away' waste, system complexities and the integrated nature of materials and pollution are quickly apparent. For example, waste incineration is expensive and poses challenges of air pollution and ash disposal. Incineration requires waste placed outside for collection to be.containerized to stay dry, and much of the waste stream is not combustible. Landfills require land availability, and siting is often opposed by potential neighboring residents. Solving one problem often introduces a new one, and if not well executed, the new problem is often of greater cost and complexity(Zhu *et al.*, 2008).

2) Aviation waste management: Airports are one of the main hubs, which produce waste. Within an airport, there are a number of stakeholders, who are responsible for this production of waste(Baxter, Srisaeng and Wild, 2018).

- Airport offices

- Retail outlets
- Restaurants, Restrooms and flight catering centers
- Air cargo operations
- Maintenance facilities
- Areas and from landscaping Construction and demolition projects undertaken at the airport

In this paper, the central focus is given to aircraft maintenance organizations, for it is one of the two areas that are accountable for the production of much of the waste in the airports.

The waste that are produce by an aircraft maintenance organization like(Mehta, 2015).

- Paper.
- Plastic (in many forms).
- Aluminum cans.
- Grease and oil.
- Electronics Light bulbs.
- Packaging.
- Solvents.
- Toner cartridges.
- Batteries.
- Fuel
- Oils and greases from ground handling equipment.

3) *Safety management is a comprehensive system:*

- Top to bottom management system
- Total study of safety in all aspects

Safety management system of different countries "Aviation safety management systems(Yeun, Bates and Murray, 2014)"

- Adopted to countries with improvement to generic system by Intenational Civil Aviation Organization.(ICAO, 2017)

To link safety management to waste management

Objectives of safety management:

Achieve safety

- For all areas of organization
- Continuous improvement
- Safety hazard identification prevention and mitigation

Objectives of waste management:

- For all areas of organization
- Waste type identification prevention and mitigation
- Continuous improvement

Methodology

1) *Data collection case study of FitsAir through interviews and questionnaires:* With regard to our initial assessment on waste management procedures followed by the Srilankan domestic airlines and the types and amounts of waste produced by the them, we chose the FitsAir aviation for our case-study as it was the main domestic air carrier that engaged in scheduled flights operations.

2) *Data collected by the Srilankan airline annual report and the recourse persons:* The amount of waste collected by the small domestic airlines when compared with large airlines are at a very low amount so in order to incorporate some of the waste that is not produced by small airlines and to compare the amount of waste produce by the small and large airlines.

3) *Data collected by other airlines operating in Ratmalana aerodrome:* In order to get a better idea on the amount of total waste output from the Ratmalana Aerodrome, we collected data linked to other organization.

A. *Case study*

The organization comprised of four Cesna-152 pilot training, where the data about the operation of the aircraft, and waste production by such operation, were collected through interviews and questionnaires conducted at the organization.

B. *Qualitative Data Collection*

As the research was conducted in the form of a qualitative study of the Fits airway, we have focused on the general procedures followed by the domestic airline, when considering the waste disposal and treatment. Higher management involvement in waste treatment of the organization needed to be explicated first, which was done by conducting interviews with the Quality manager and the Manager of engineering.

C. *Interview with the Quality manager*

In the interview with the quality manager of the FitsAir aviation association, the main points conversed, were, the top management's involvement in the organization's waste management, the areas, which needed further upgrading, and whether there were regular interval checks, conducted by the top management or the organization's quality management department, in order to keep the standard of the waste management processes, that was already in place.

Through the interviews, we were able to grasp that the method used for waste management in the organization was not accurately regulated. The amount of involvement by the organization's top management towards waste management was minimum. There was no solid method of collecting and disposing of some of the waste produced by the organization. There was no documentation process in order to clarify the amount of waste produced by the organization and thereby no method, which aids the organization to understand whether the waste produced by the organization has increased and what amount of waste increment, is being introduced, to the environment as harmful untreated waste.

The methods that were followed, were considered by the organization as not adequate to cater for amount of waste being produce by the organization is increasing with the growing of the organization. This will lead to a possible high risk to the environment protection and a need for system that adept with the improvement of the organization was clearly noticed as needed.

The waste materials that were more frequently produced and what waste material that were less produced and what are the more hazards types of waste that was produced by the organization were discussed. What is the area of waste that needed the immediate attention if a process were to be introduced for the organization?

4) *Interview with the manager engineering:* The interview conducted with the fits air manager engineering comprise of similar questions to that were asked by the quality manager of the organization but more concentration was given on waste produce by the maintenance activities of the maintenance operations of servicing, repair and modification.

The waste produced were documented according to type of waste produced and the amount of waste produced and the occurrence of such waste produced in maintenance operations. When considering the whole organization, the types of waste produced by the organization were as such

- Paper
- Plastics
- Aluminum
- Grease and oil
- Electronic light bulbs
- Packaging
- Toner cartridges
- Batteries
- Fuel
- Oil grease from ground handling equipment

When considering the maintenance organization, the amount of waste collected in conducting maintenance activities can be categorized as mainly liquid waste, which includes

- Hazards waste materials
- Fuel
- Oil
- Lubricants
- Hydraulic

The second method used to collect facts from the organization followed by the interview was, once we have understood the top management's commitment towards waste management to get the ground idea of how the waste management operated. In order for this, a questionnaire was prepared by use taking into consideration the waste types taken by interviews and the probability and severity of the waste produced and the waste management process in place already by the organization.

Existing waste management process in the organization

Contemplating the information collected, the waste management of solid waste like paper plastics and batteries and electric bulbs and the airport authority manages other solid waste and regulated by the municipal council in which case the solid waste from making significant damage to the environment is mitigated. So, although the occurrence of these materials was too growing to higher amount the system followed would be adequate to control.

Although the organization process for reducing solid waste is properly managed the liquid waste produced by the organization is not given the proper consideration and it is not regulated by the local body or the airport waste management system. The liquid waste that was collected by the organization was not deposed to the environment in a proper method. Consequently, this liquid waste collected by the organization was a highly possible threat to the environment, and when considering the organization due to an absence of a proper dispose method it was taking the storage space of the organization which is a cost to the organization.

Mainly waste like

- Grease and oil
- Fuel
- Oil
- Lubricants
- Hydraulic

According to the maintenance manual of the Cessna 152, which is the training aircraft used by many of the aviation organization in the Ratmalana aerodrome. There are no maintenance activities, which produce unavoidable waste.

On the daily inspections of the aircraft, it needs to check its fuel quality by removing a sufficient amount of fuel through the drain of the aircraft. In this case, an amount of 0.5 liters of fuel is taken per aircraft and at any instant, the fuel is found not to be at its desired quality the fuel needs to removed completely and re-fueled. This type of situation can add to the regular amount of fuel waste produced by the

organization. In case of such occurrences, the extra amount of degraded fuel more or less, is disposed by the organization in a manner, which is not eco-friendly. When considering the daily amount of unavoidable fuel removed. This amount also adds up to a high amount when taken for a long period of time (year).

At the 100-h inspection of the aircraft, it needs to do a full oil change where the remaining oil from the aircraft is taken out completely. The inspection occurred according to fight hours but at least once per aircraft within two weeks' time.

At each 200-h inspection, the hydraulic system of the aircraft brake system needs to be refiled and bleed out to remove entrapped air from the system.

Before all maintenance, activity aircraft need to be cleaned by using water and detergents

In addition, when considering the amount of waste produced by the organization and the probability of such waste produced oil was a major concern. The organization used piston engine aircraft for its flights, which needs to change it oil completely every two weeks. A deep study was conducted about oil waste in the organization.

The organization comprised of four Cessna-152 pilot training aircraft which used AeroShell W-100 lubrication oil. The oil needs to be completely changed at each 100h service which occurred every two weeks the amount of oil used for an aircraft is 7 quarter (6.624L) and about 6 quarters (5.678L) of oil is removed as used oil per service a very small amount (0.5L) of used oil was kept for the reuse within the organization.

D. Activities conducted

1) *Actions of oil purchasing and oil storing*: The methods of oil ordering were done on the base of stock remaining. A minimum amount of stock in the store was kept at 35 quarters (33.122L) and this amount was re-stocked by 250-255 quarters. The storing of oil was done according to the guidelines given. The release of oil to service was done as 7 quarters. There was no method of calculating the amount of oil used for annum to get the amount needed for the entire year. The main problem being a small organization and the number of flying hours of aircraft being inconsistent.

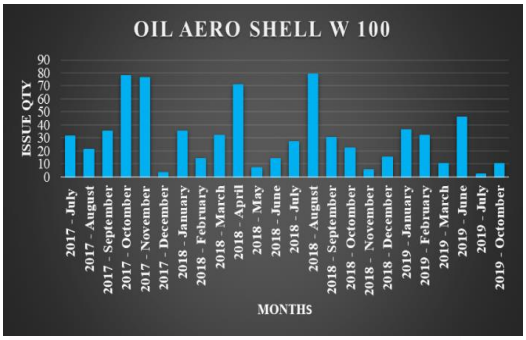


Figure 3-12. Oil usage per month graph.

2) *The amount of oil used per service:*For the 100h service of each aircraft total of 7 quarters were needed and amount of oil removed from the aircraft as used oil was about 6 quarters per each service per aircraft in the below given chart 44 weeks were taken for the calculation for a year

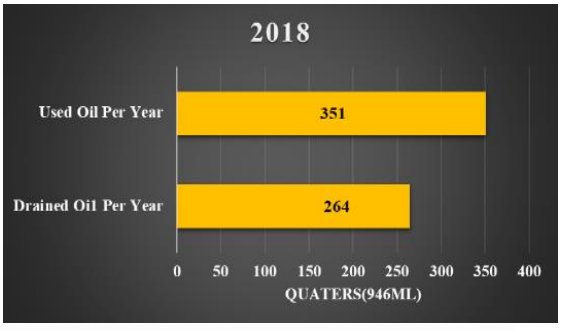


Figure 3-13. Amount of used oil per drained oil in 2018. The storing of used oil

After the removal of used oil, they are collected in containers and transferred to the stores. Then from the stores a very small amount is reused for the organization works where the rest of oil needs to be removed from the organization.

In FitsAir, there are certain consumers of these used oil but the amount of used oil taken from them is rather low when considering the amount of oil that is removed.

- Sales to individuals, sawmills, furniture makers, timber producer.
- Taken by block makers to be used as lubricant in mold equipment.
- Taken by service centers for maintains activities of vehicles.

However, as the amount of removing oil to sales of oil ratio is high, there is a high collection of oil within the organization. That need to be removed as the space occupied by these containers is a negative factor in the organization so the other method that is commonly used is to dump the removed used oil from the aircraft without filtration directly into the environment.

The outcomes of visit

- Identifying the methods used in the organization on purchasing and storing of oil in the organization
- The quantity of oil need and for a servicing of the aircraft in the organization the amount of used oil removed from the aircraft
- The procedures followed on removing the used oil from the organization
- What are the main problems associated with the waste oil management in the organization?

The problems in waste oil management

- The direct environment effect of dumping oil was not regarded as a concern of the organization. The main goal of the organization being to remove it from the organization.
- Recycling of used oil by the organization to reduce the environment effect was not seen as cost affective as the amount of oil removed per service was low and the limited area and the manpower of the organization was also a concern.
- There was no proper procedure to remove the used oil from the organization.

After conducting a deep analysis on the production of oil waste by Fits Aviation we further concluded that there is a significant amount of liquid waste produced by the organization, due to its maintenance activities. Considering organizations which use similar types of aircraft fleet for its flight's operations, we were able to find data within the aerodrome of the Ratmalana airport. As these aircraft need to be maintained in a similar manner the amount of waste produced by each fleet can be considered more comparable to that of FitsAir. These organizations are also operating under the Ratmalana airport the liquid waste problems faced can be identified as identical and the environment affect due to them as such.

E. Objective combination

The main objectives for an effective and efficient waste management system need to be met by the combination the safety management system concepts for developing our waste management system. The interviews conducted with top management of the case study organization clearly proved that there was a lack of top management involvement in managing the waste produced by the organization.

Results

A. Srilankan airlines data analysis

By considering the data, we have looked into the per flight waste generation of the fleet of Sri Lankan Airlines with respect to other domestic air lines in sri lanka. Hence we have collected and anlyzed data from the domestic airlines by inspecting and interviewing organization managements., furthermore, we have analyzed data from maintenance program document. We have found the detailed quantities of the aircraft maintenance waste per 750FC and 6000FC. By taking these amount we have found the waste generations per year 2017, 2018, and 2019.

The hazardous waste fluid materials that are generated through the maintenance process are fuel, engine oil, Auxiliary Power Unit oil and hydraulic fluid. Quantity of waste per for one site emergency have been found from the Maintainance Planing Document (Cedex, 2010). Also have found the waste generation per flying hours 750FC. Therefor due to the total number of aircraft services done at the end of year 2017, 2018 and 2019. We have taken the same path to find the total waste per year for the flight hours 6000FC (C & D checks).

Table 16. Total waste of waste per flying hours 750FC.

Waste Material	**Total Waste 2017 (Liters)**	**Total Waste 2018 (Liters)**	**Total Waste 2019 (Liters)**
Fuel	1440	1560	1620
Engine Oil	168	728	756
APU Oil	192	208	216
Waste Water	912	988	1026

Table 4-1 depicts the types of waste produced and the total amount of waste produce per each type per year in the consecutive years of 2017,2018 and 2019. The waste have been produced 750H servicing of the aircraft. In Srilankan airlines the amount of waste produced in the table 4-1 it can be seen that in each case the amount of waste produced have been increased with each year and the highest amount of waste have been produce in fuel waste collected by the organization and the followed by waste produced by waste water and there after engine oil and last due to Auxiliary Power Unit oil. So, the amount of waste produce as a total in engine oil and fuel has been at a high amount.

The table 4-2, depicts the types of waste produced and the total amount of waste produced per each year in the consecutive years of 2017,2018 and 2019. The waste products are produced of 6000H servicing of the aircraft. In Srilankan airlines the amount of waste produced when considering the types of discussed in the table 4-2 it could be seen that in each case the amount of waste produced has increase with each year and the amount of waste produce is highest in fuel waste collected by the organization and the followed by waste produced by waste water and there after engine oil and then add amount of waste by hydraulic fluids and thereafter at last due to Auxiliary Power Unit oil. So, the amount of waste produce as a total in engine oil and fuel is at a high amount.

Table 4-17. Total waste Srilankan airline at waste per flying hours 6000FC.

Waste Material	Total Waste 2017 (Liters)	Total Waste 2018 (Liters)	Total Waste 2019 (Liters)
Fuel	1440	1560	1620
Engine Oil	168	728	756
APU Oil	192	208	216
Waste Water	912	988	1026
Hydraulic Fluid	348	377	391.5

B. The Domestic small airline data analysis

Going through the domestic aviation organization maintenance program, we had analyzed the same materials, which is can risk the organization's environmental safety. the table 4-3 shows the data gathered about the aircraft operated similar to the operation of case study organization and with the information of aircraft fleet.

Table 4-18. Aircraft fleet of organizations in Ratmalana Aerodrome.

Aviation Organization	Aircraft Type	Number of Aircrafts
Fits Air	CESSNA 152	4
Asian Aviation	CESSNA 152	3
Sakurai Aviation	CESSNA 172	2
Skyline	CESSNA 152	3
		total =12

The table 4-4 shows the types of waste resulted by waste that have been produced by the organization and the amount of waste produced daily and at each 100H check of the aircraft mention in the above table. The information below were calculated according to maintenance activities given in the Maintenance Programme document and with the organization procedure.

Table 4-19. Waste produce at daily and 100H check by fuel, oil, waste water hydraulic fluid.

200H check (mounthly)			Total waste per year			
Liters	Gal	Total waste (liters)	daily check (liters)	100H check (liters)	200H check (liters)	total waste per year
10	2	120	7200	5760	5760	18720
25	5	300	0	14400	14400	28800
5	1	60	0	0	720	720
2	0.4	24	3600	1152	288	5040

Table 4-20. Waste produce at 200H and total waste per year.

Waste Material	Daily Check			100H Check (2 weeks)		
	Liters	Gal	Total waste (liters)	Liters	Gal	Total waste (liters)
Fuel	2	0.4	24	10	2	120
Engine Oil	0	0	0	25	5	300
Hydarlic Fluid	0	0	0	0	0	0
Waste Water	1	0.2	12	2	0.4	24

The table 4-5 shows the types of waste occurring dur to the type of waste been produced by the organization and the amount of waste produced per 200H check and the total amount of waste produced by the organization per year for the aircraft mention in the table 4-5. The table 4-6 data were calculated according to maintenance activities given in the Maintenance Programme document and with the organization procedure

Table 4-21. Waste production comparing of Srilankan airlines with Ratmalana aerodrome aviation organizations

Waste Material	***Sri Lankan Airlines***	***Domestic Aviation Organization***
Fuel	*18720*	*1620*
Engine Oil	*28800*	*756*
Hydraulic Fluid	*720*	*216*
Waste Water	*5040*	*1025*
APU Oil	*216*	

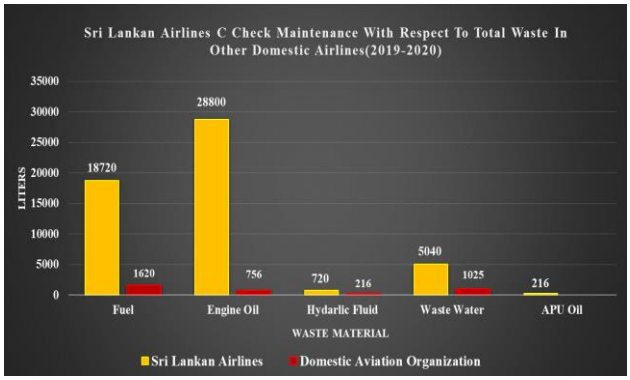


Figure 4-14. Amount of waste produce per year 2019-2020.

The figure 4-3 compares Srilankan Airlines waste generations per the year 2019 with respect to other domestic aviation organizations waste generation. Consequently, through analyzing the graph we could see from total fuel waste 14% of waste fuel has been generated from Srilankan aviation C & D check maintenance. But only 2% of wasted engine oil has been generated with respect to total engine oil waste generated from other domestic aviation organizations. Therefore, domestic aviation industries must highly concern about engine oil waste. Thus 30% of hydraulic fluid waste have been generated from Sri Lankan airlines C & D check maintenance with respect to other organizations. So, it must highly concern on the Sri Lankan aviation. Waste water is not concerned since it is organic waste which is not hazardous. Also, 216L of Auxiliary Power Unit oil waste generated only from Srilankan air lines organization. Through the analysis we could see the total aviation hazardous waste fluids generations by taking the total amount of waste materials of all aviation organizations in the country.

C. Waste Generation Projections for 2025 by Income Region

comparing the projections of 2025 of waste generation of low middle-income countries sri lanka commercial aviation organizations fluid waste generation will be 1.86% of total waste generation of all low middle-income counties.

Wherefore, we can use safety management concepts for effective waste management, considering environmental aspects and per organization standards.

Conclusion

The research provided definitive proof that the waste, which is spawned by the aviation industry, is increasing due to its escalation and with the increase of the waste production. Therefore, organizations are going into waste removal and disposal methods that can harm the environment at a very high rate. We have mentioned how the necessity of a proper system of management to mitigate and prevent the waste production and if the waste production is un avoidable, then use of treatment before disposal to environment is needed. Through the analysis of aviation maintainance organization waste we included waste risk management as a safety management system concept to analys the levels of hazardous waste also as a waste minimization process. Thus through the analysis of risk management for a continouce waste management sytem waste management assurances and waste management promortions are recommended for the implemented waste management system. The amount of waste is always increasing and any system that is put in place need the total commitment from the organization; from the top management to the bottom. Waste management policies and objectives are recommended to the impimented waste management system and as a safety management system concept. With the basis of safety management system concepts, when introduced a waste management system; need to be able to adept with the organization development and a methodology to

continuously improve as stated. The aviation organization small and large has not given the due care to the amount of waste that they are producing and removing into the environment. Although, the amount of waste produced by small airlines are not significant when compared to large airlines, when it comes to hazardous waste such as fuel and oil, they are continuously released to the enviorenment, without any treatment though the damage to the eco system will be high.

Recommendations

A. Waste management policy and objectives

- Purpose of waste management system
- Benefits of waste management system
- Positive waste management culture
- Waste management values
- Priority of waste control
- Waste management policy statement
- Organization structure

B. Waste management risk assessment

- Categorization of risk
- Severity
- Probability
- Risk matrix
- Mitigation process
    - Avoidance
    - Reduction
    - Segregation of exposer

C. Waste management assurance

- Waste management inputs
- Acceptable level of waste disposal
- Waste management performance monitoring and measurement
- Waste disposal hazard reporting system
- Occurrence reporting – Flow chart
- Waste management quality database – WQD

D. Waste management promotions

- Waste management training
- Types of training
    - Initial training
    - Recurrent training
    - Update training
- Documentation of training program
- Presentation of training
- Validation of training
- Training program review
- Training files

Limitations

- Unavailability of waste collection data document
- Data speculated by
    - Inventory records
    - Maintenance planning document
    - Organization annual report
- Organizational waste limitation
- The amount of research related to aviation comprehensive waste management limited
- The current global situation preventing the application of the system to a large aviation organization to measure its effectiveness

Areas for Further Research

- With sufficient accurate data from each organization to continue the waste type reduction process
- Implementation of waste management system for large organization to evaluate effectiveness

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Controlling Parked Vehicle Interior Temperature Using Renewable Energy

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Abstract: A parked vehicle cabin can be treated as a nearly closed volume. So, when an automobile is parked under sunlight the solar radiation heats the interior to extensive temperatures of above 60°C. These extreme temperatures reduce the cabin thermal comfort of the occupants, especially until the automobile's in-built cooling system brings the temperature to a comfortable level. The extreme temperatures in the cabin have also led to several heatstroke victims and even deaths of occupants in parked automobiles. These extreme conditions also degrade cabin materials. This research focuses on developing partly portable cooling equipment based on the vapor compression refrigerant cycle that is powered by solar energy for a car cabin.

The equipment was sized for a Suzuki Wagon R – 2015 automobile, based on the local heat loads that were gained in this research. Also, two Computer simulations were done to determine the cabin conditions with and without the designed equipment. Further verifications of these results were done by testing a prototype of the design.

The results from computer simulations and test results both confirm the reduction in cabin temperature to below 44°C. Further developments are necessary for this model to make the parked car cabin completely safe for occupants. With the current results gained using the prototype developed, the car cabin thermal comfort has increased by a huge margin, where the temperature has reduced from above 60°C to below 44°C. This paper focuses on the simulation segment of the research conducted.

Keywords: Heat distribution, Cabin cooling, Simulation

Introduction

Automobiles are an essential part of human lives in the modern civilization. It is estimated that there are more than a billion passenger cars worldwide [1]. When these automobiles are parked outdoors thermal accumulation leads to several issues, out of which some are minor, and some major problems such as human deaths due to heat strokes while being in a parked car needs necessary attention of researchers to find proper solutions.

A parked automobile with all windows closed is nearly a closed volume. When such an automobile is parked outdoors, the solar radiation accumulates inside the cabin and the cabin temperature rises to extreme temperatures. The solar radiation reaches the cabin by direct and diffused solar radiation through windows and by the conduction of the absorbed heat by the automobile roof into the car cabin. Earlier researches as well as this research shows that the cabin temperature can reach to temperatures high as 65° C [2]. The heat accumulation inside such a car cabin can be so extreme that it has a possibility of leading to heat strokes of passengers [4].

The temperature increment is also extremely discomfort able for a passenger returning to a closed car cabin. The automobile's in-built air conditioner usually takes a few minutes to reduce the cabin temperature to comfort conditions recommended [6]. This is a minor problem that arises due to the heat accumulation in a closed car cabin. The major problem is the fact that the heat accumulation can lead to heat strokes, if a passenger is left inside a closed car cabin which is parked [5]. According to Llama et al, [6] When a human body is exposed to high temperatures or extreme heat the body first reaches heat exhaustion. Heat exhaustion is caused by loss of water and electrolytes due to sweat. If unattended this condition could lead to a heat stroke [3].

Research problem

The increment of temperature due to accumulation of heat in a parked closed automobile cabin.

Problem Solution

The proposed solution is to run a solar powered partly portable air conditioning unit to cool the car cabin when it is parked, and engine switched off. The air conditioning unit is a portable equipment, with flexible ducts and window mounted duct end parts. The refrigeration cycle is based on the vapor compression cycle and R132-A is being used as the refrigerant.

One of the duct-end parts, mounted to the windows is to admit fresh air from the outside ambient air around the car. The air is circulated through the condenser and compressor and in to the second duct-end which expels the heated air to the outside. This is the cycle used to cool the condenser of the refrigeration cycle and to cool the compressor. The second air side cycle is in the evaporator side. Return air from the cabin is admitted into the evaporator chamber which is separated in the unit. Then the return air is passed through the evaporator into the car cabin. The return air in turn is cooled. Both these air side cycles of condenser cooling with ambient outside air and cabin air cooling with the evaporator are completed with 2 circulation fans on each cycle. During a power surge or if the temperature rise in the equipment is too high, the refrigeration cycle stops and dampers are used to open the return airline to the outdoors, and the fresh air into the cabin to control the heating. Once the equipment cools down or enough charging is achieved by the batteries the refrigeration cycle powers back.

Methodology

A. Evaluation of heat distribution of the automobile cabin

Temperature data will be collected of the outside surface temperatures and the inside air temperature of the cabin. Then by using the outside air temperature readings a CFD simulation model of the car cabin for the worst scenario, which is where the temperatures gathered are the highest. The simulation is done in this case to determine the temperature pattern of the air inside the cabin

B. Simulation of cabin interior using Computational fluid dynamics (CFD)

The temperatures we obtained in the data collection stage was utilized to lay the basis for the CFD simulation. A sketch was generated that resembled the geometry of the cabin that we chose for testing. The necessary boundary conditions were assigned to the surfaces to accurately simulate a real-world environment.

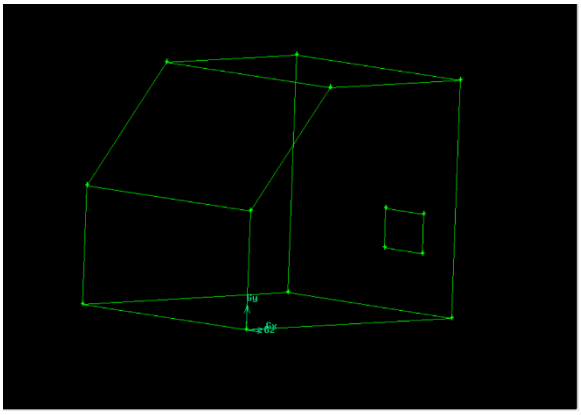

Figure 15: Geometry of cabin completed with GAMBIT

C. CFD simulations of the car cabin with the designed system

The next step to be followed is to simulate the conditions in the cabin after the air conditioning unit has been placed in the cabin. The unit will be placed in the rear passenger seat with an opening at the window to transport air to and from the condenser. After the completion of the simulation by using results from the post processing the areas with highest temperatures will be identified and the unit will undergo changes to both its physical and software components. In order to determine the changes, the air inside the cabin would undergo we decided to run simulations with the prototype positioned inside the car cabin. The basic settings from the previous iteration was carried into the new simulation and the car cabin geometry was subjected to changes to accommodate the prototype. The first change was to insert the velocity inlet to the cabin. This was done by making a diffuser that has a similar flow rate to that of the real-world example. The inlet was placed in the rear boundary condition and it was positioned close to the underbody of the car.

The heat load due to solar radiation is main contributor to the temperature rise in the car cabin. Therefore, it is of great importance that we employ a practical methodology to determine the heat gained due to solar radiation. The solution for this issue can be addressed using one of them mathematical models that is present within the Fluent software. The radiation can be virtually simulated using one of the models available in the selection menu. Rosseland, P1, Discrete transfer model, Surface to surface and discrete ordinates are the list of solar radiation models that can be applied for solar radiation problems. The model we chose was Discrete Ordinates (DO) radiation model. It is a model that is well suited for

- Automotive climate control applications
- Thermal comfort modelling scenarios in buildings

Simulation Results

A. Heat distribution without prototype

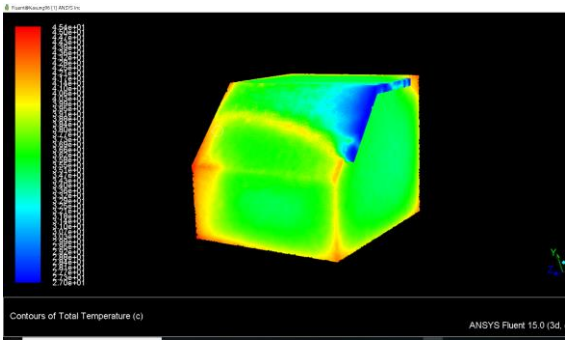

Figure 16: Isometric view, Heat distribution without prototype

The above figure is the representation the temperature distribution of the parked car cabin. The maximum temperature observed in this test result is 45° C. The edges of the car cabin seem to have accumulated more heat than the rest of the surfaces. The mean temperature of the surfaces was between 35 to 38 ° C. The roof, left and right panels showed a similar amount of heat gain and therefore had similar temperature ranges. The rear panel also showed similar thermal characteristics to other panels, but the centre portion of the surface shows a region which is transitioning to the yellow region which indicates that the temperature in that area is

steadily increasing. A change in temperature is observed at the windshield which shows a mixture of temperatures. The temperature of the inner region has remained fairly constant at 32° C. The top right corner has received

some degree of solar irradiation as the pointed edge has a temperature higher which belongs to the yellow region which is analogues to a temperature range of 38 to 42° C. According to the result produced results we can see that the green region has formed a shape that has almost surrounded the lower temperature zone at the centre of the passenger compartment. The light blue region according to the settings that have been applied shows a temperature range that spans from 31 to 34 ° C. A green band which is the colour that represents temperature values 34 to 38° C has originated from the underbody and travels all the up to the midpoint of the windshield.

B. Heat distribution with the prototype inside the cabin

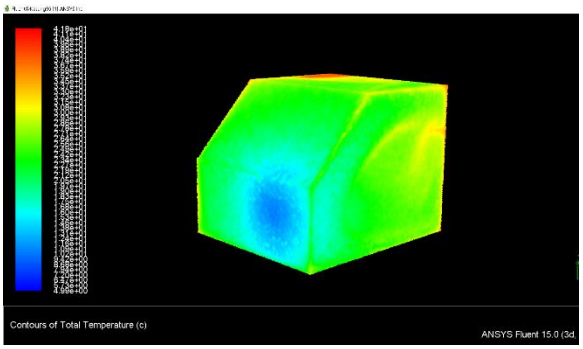

Figure 17 : Isometric View, Second iteration

The second iterations according to the figure shows a maximum temperature value of 42° C. The maximum temperature was obtained at the rear and a side panel surface. The whole volume is mostly covered in green which represents the temperature band from 21 to 26° C. The front panel has a large light blue patch that corresponds to temperatures between 13 and 20° C is due to the heat transfer that occurs between the cabin body panel and the chilled air supplied by the prototype. The interior temperature however is largely dominated by the green region which shows that the temperature inside the cabin has been reduced by the placement of the prototype. Before the simulation was started the interior was initialized at a temperature of 32° C. The prototype according to the simulations has reduced the interior temperature by about 3° C.

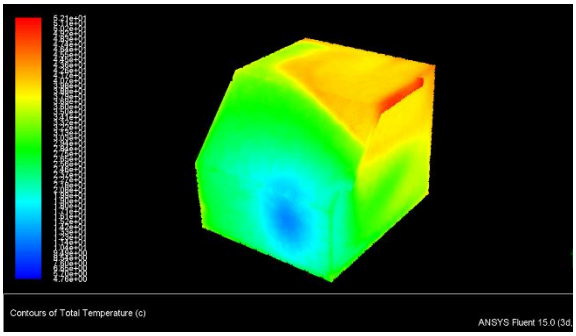

Figure 18 : Isometric View, Third iteration

The final iteration of the simulations was done with a window duct in place which acts as an outlet for the air inside the system. The window is placed close to the top edge of the car cabin and run a length that is equivalent to the length of the window in the real-world example.

As demonstrated below the mesh was oriented in a such a way that the sun`s radiation would fall on to the roof of the car cabin. The maximum temperature observed in this exercise was 52° C. The edge of the roof that is joint with the left body panel has the maximum temperature level according to this figure. A considerable portion of the roof and the left body panel is in a temperature range of 40 to 50° C. The interior of the car was set at 32° C before the simulation was commenced. As per the below figure the region that that falls under the region of 26 to 33° C temperature band has reduced dramatically. The effect is clearly visible as the temperature in the region as the 32° C temperature has been reduced to values in between 25 and 16° C.The light blue region also extends along the length of the left body panel and the temperature has made quick transition to the

30 ° C range and continued its increase towards the upper most limits of .The windshield region expresses a range of temperature levels from the lowest to the highest. According to the below figure the lower end of the windshield is belongs to an 18-26° C temperature band. The temperature then makes its way towards higher temperatures mainly due to the solar irradiation and the total temperature reaches its highest value in the left corner of the windshield. The roof region has no temperature level that falls within the temperatures lower than 26° C.

Conclusion

The simulations we conducted showed us the amount of solar irradiation on a car parked under the direct sunlight. The cabin interior temperatures rose to 42° C and the thermal comfort within the cabin was at a lower level. The placement of the prototype helped to reduce the cabin temperature by 3 ° C when solar radiation is at its peak and by 13° C when it is moderate levels. The placement of the ducts on the windows together with the unit helped further reduce the cabin temperature.

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